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National Center for Adaptive Neurotechnologies

Adaptive Neurotechnologies

Rhythms Reflexes Rehabilitation

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National Center for Adaptive Neurotechnologies
Wadsworth Center, New York State Dept of Health

Two Recent Advances

- Recognition that the CNS changes throughout life. *Activity-dependent plasticity* is occurring everywhere.

- Hardware & software for complex real-time interactions with the CNS that initiate & guide plasticity.

Unprecedented opportunities for adaptive interactions:

New insights

New therapies

Adaptive Neurotechnologies

- The CNS interacts with the outside world & the body through peripheral nerves, sensory receptors, & muscles.
- Adaptive neurotechnologies ***replace***, ***restore***, ***enhance***, ***supplement***, or ***improve*** these natural interactions.
- These technologies typically adapt their behavior to the CNS & often induce adaptive plasticity in the CNS.

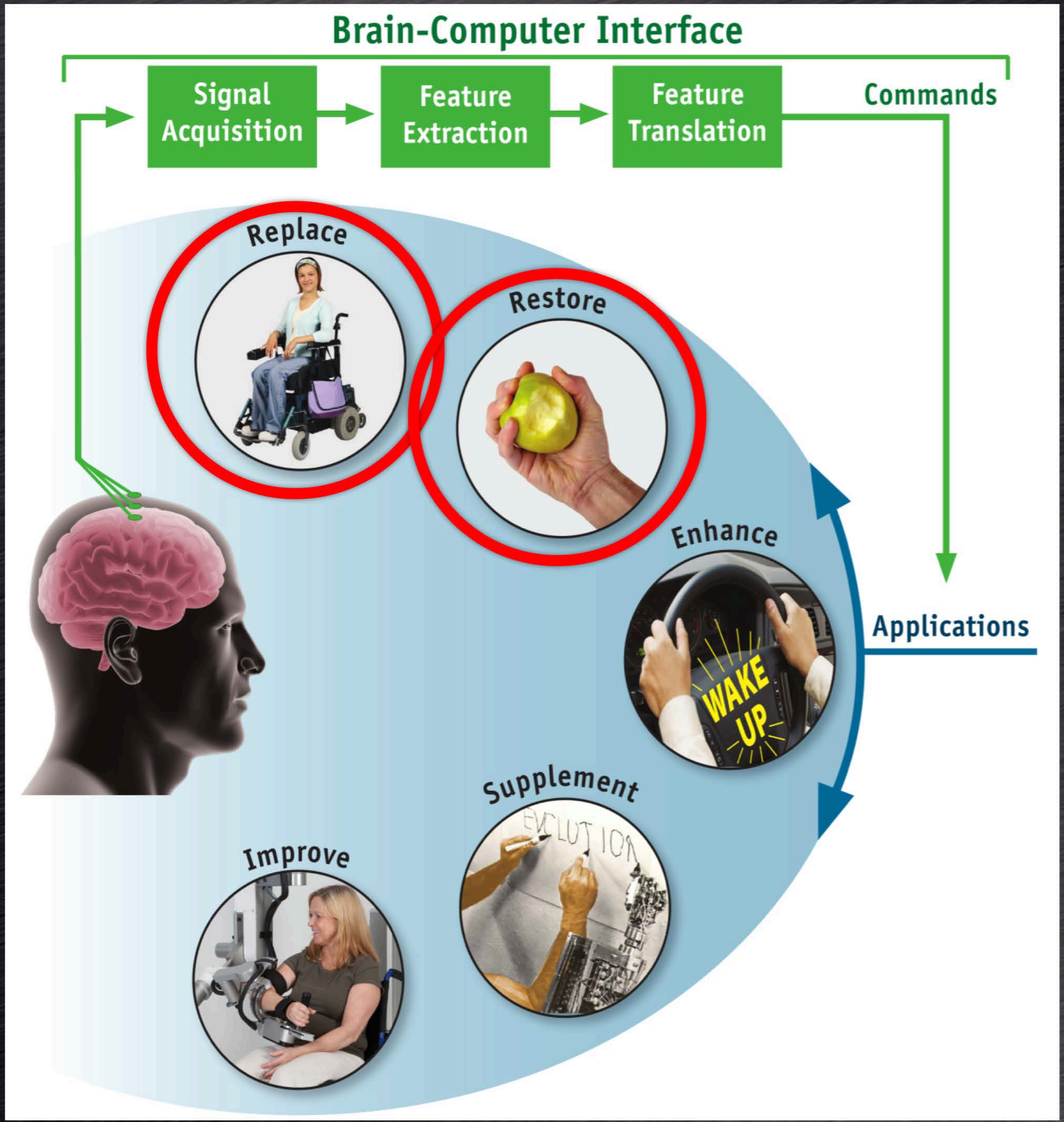
Adaptive Neurotechnologies

- BCIs for restoring communication and control
- BCIs for stroke rehabilitation
- ECoG for pre-surgical mapping of cortical function
- Reflex conditioning for rehabilitation after spinal cord injury: Targeted Neuroplasticity

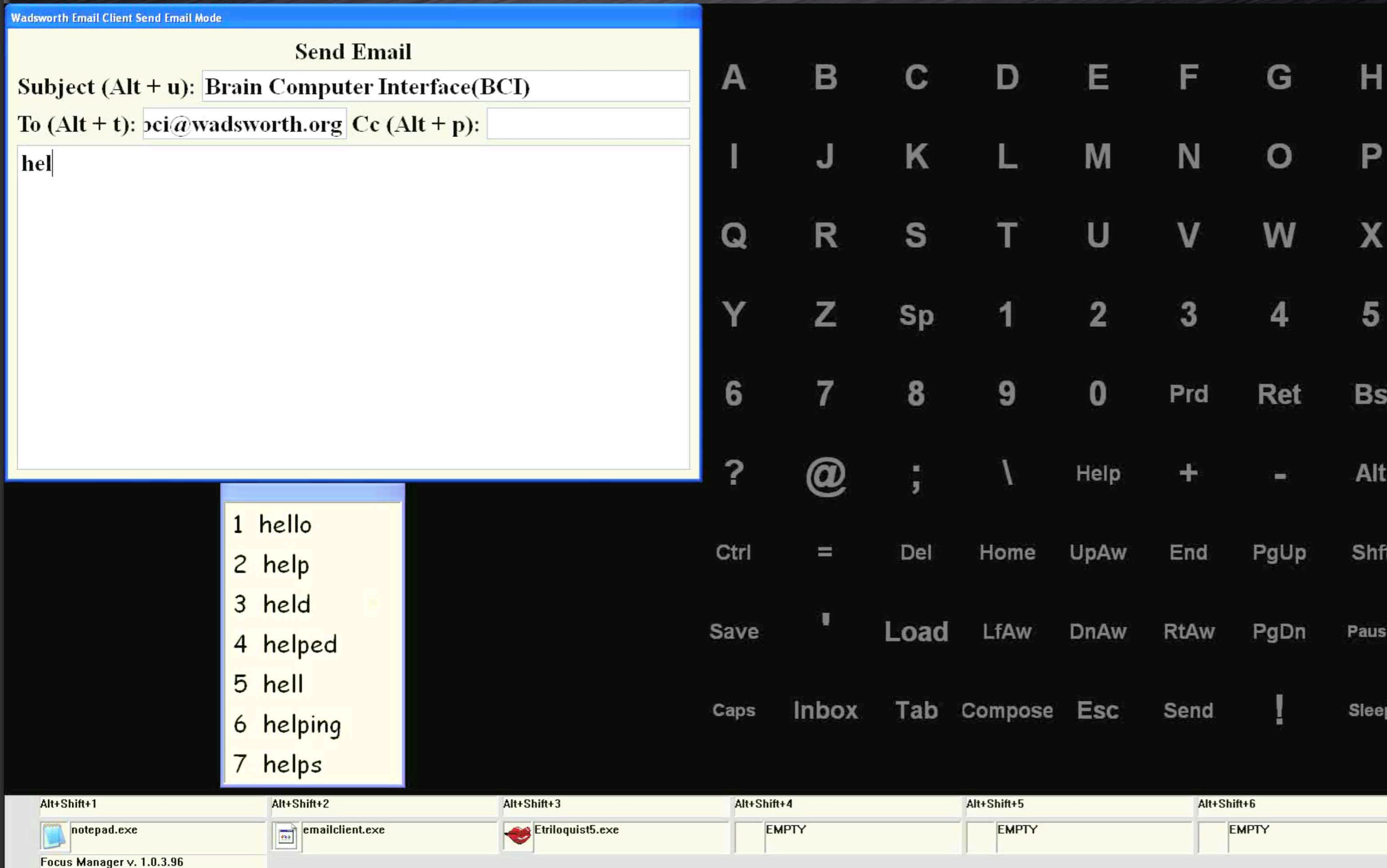
What is a Brain-Computer Interface?

The CNS produces outputs that act on the world or the body. All its natural outputs are neuromuscular or hormonal.

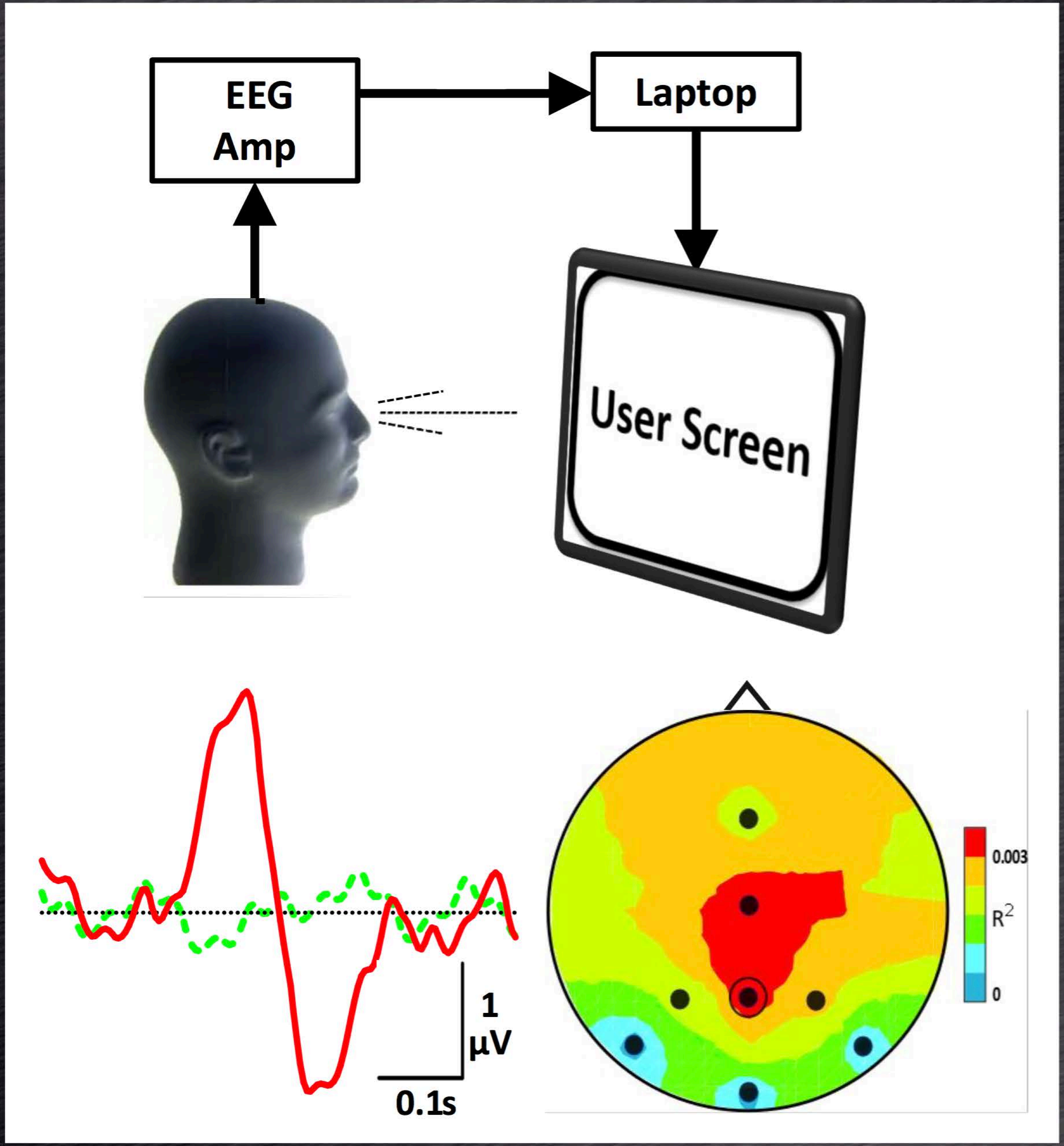
A BCI measures CNS activity and converts it into artificial output that ***replaces****,* ***restores****,* ***enhances****,* ***supplements****, or* ***improves*** *natural output, and thereby changes the ongoing interactions between the CNS and its environment.*


Brain-Computer Interface
Signal Acquisition
Feature Extraction
Feature Translation
Commands
Replace
Restore
Enhance
WAKE UP
Applications
Supplement
Improve

Email with the Wadsworth BCI Home System

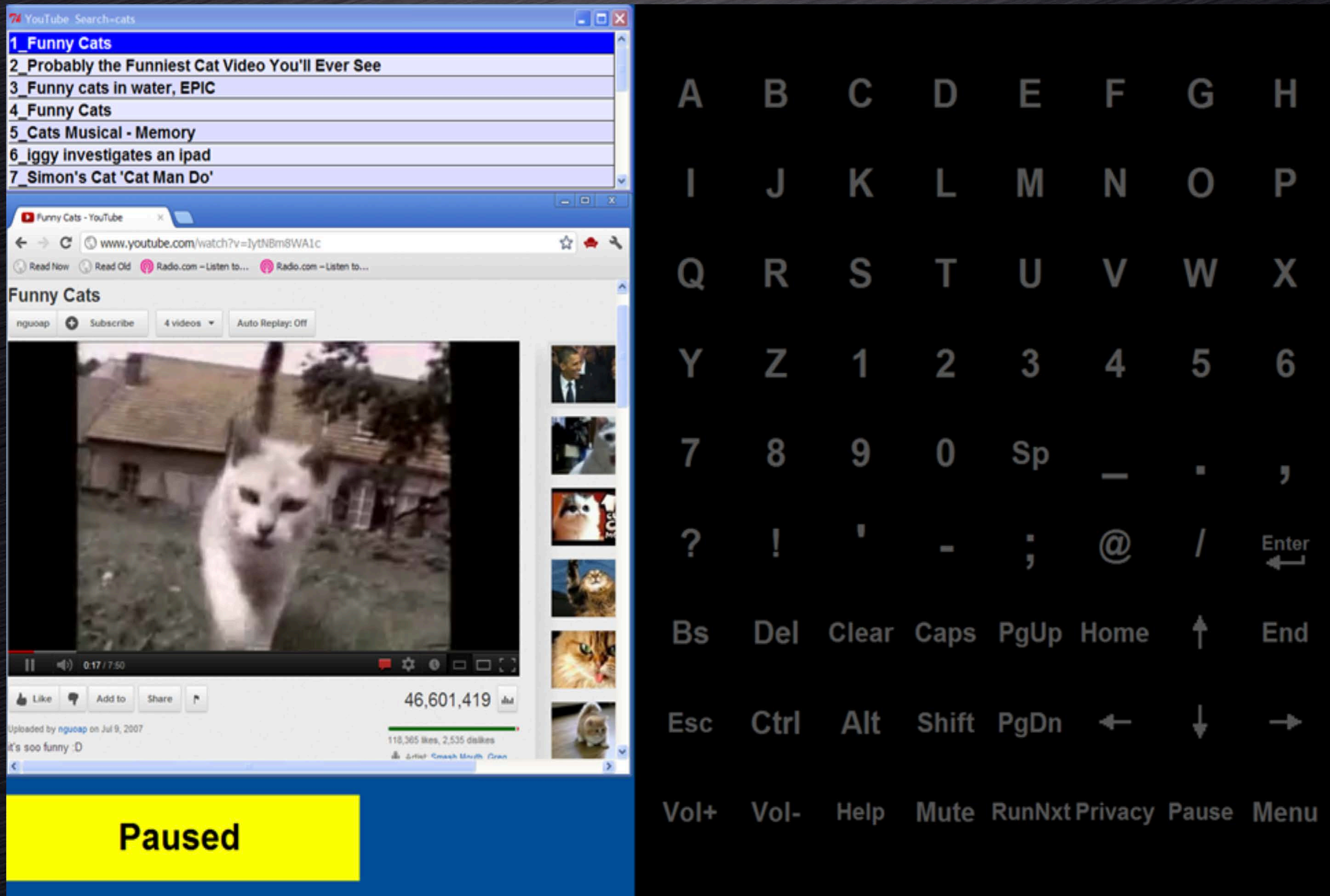


P300 Evoked Potential



Donchin et al. 1988,2000

BCI Home System Applications



Training Users and Their Caregivers

Vaughan et al.

Asked to describe BCI impact on his life, the first user wrote:

Subject: Re:
From:
Date:
To: Jonathan R. Wolpaw
Cc:

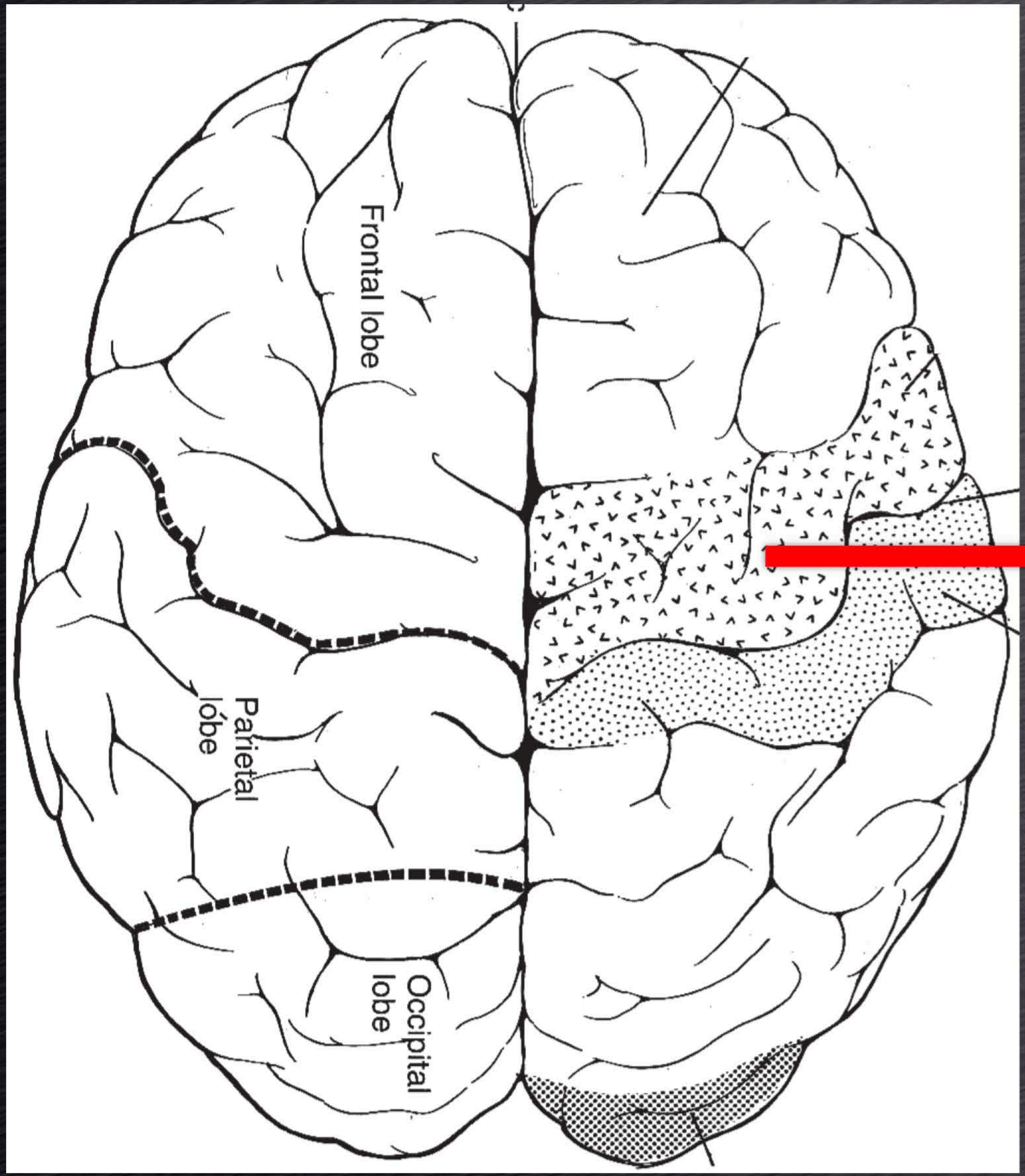
No problem.

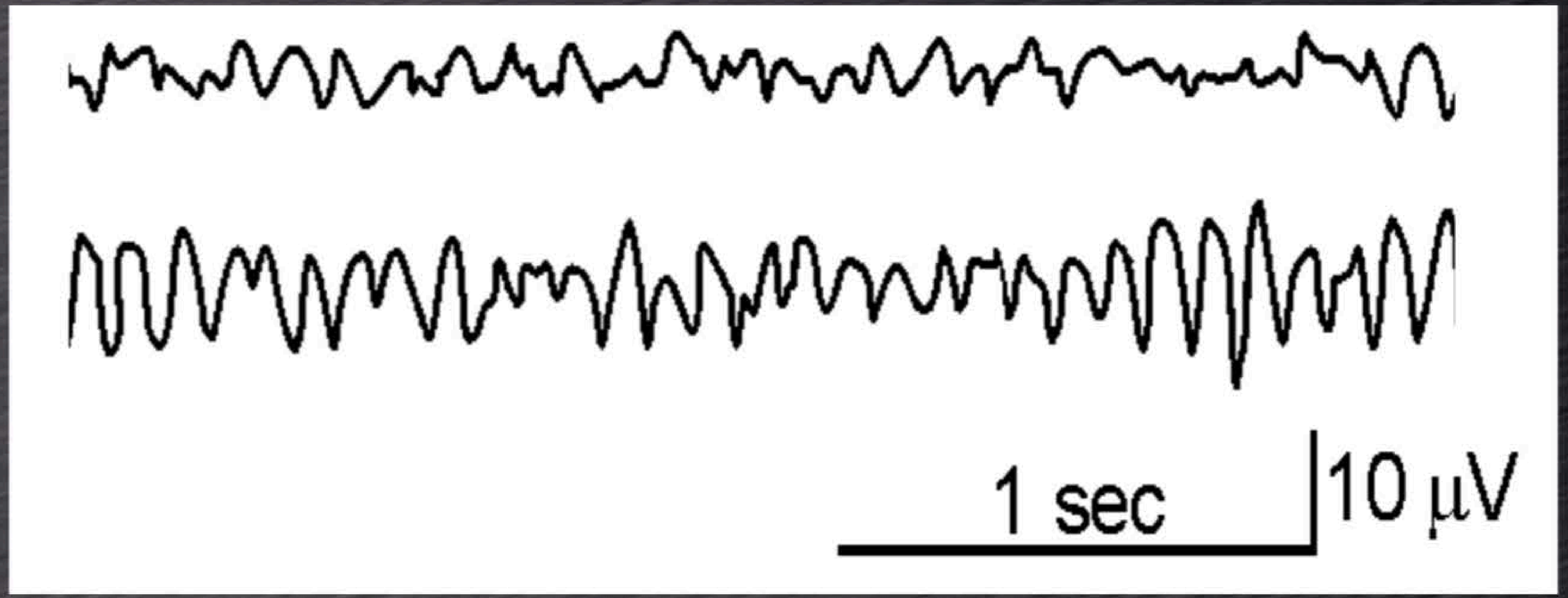
I couldn't run my lab without BCI. I do molecular neuroscience research and my grant pays three people.

I'm writing this with my EEG courtesy of the Wadsworth Center Brain-Computer Interface Research Program (www.wadsworth.org)

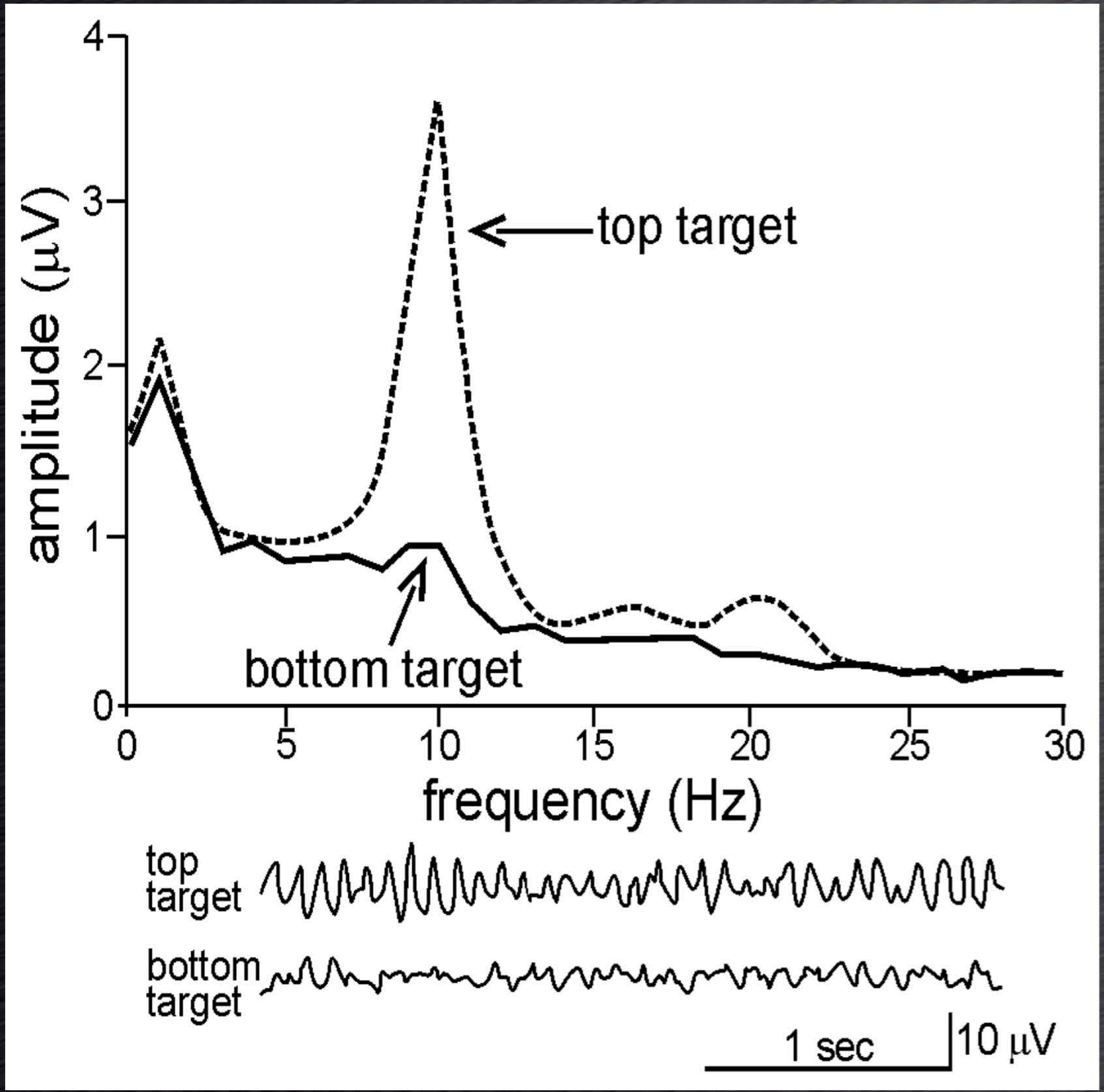
Sellers et al. ALS, 2010

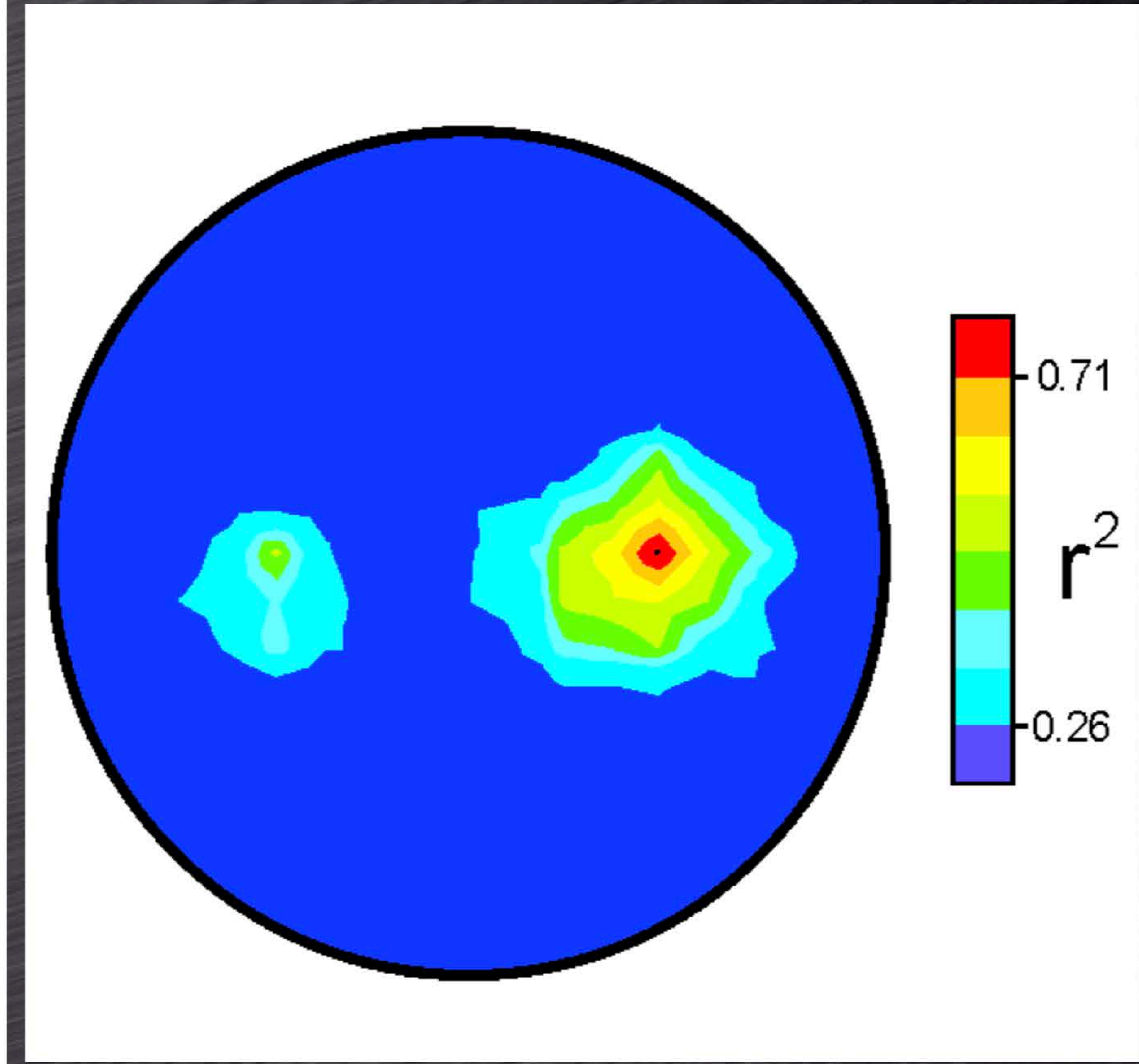
EEG Sensorimotor Rhythms





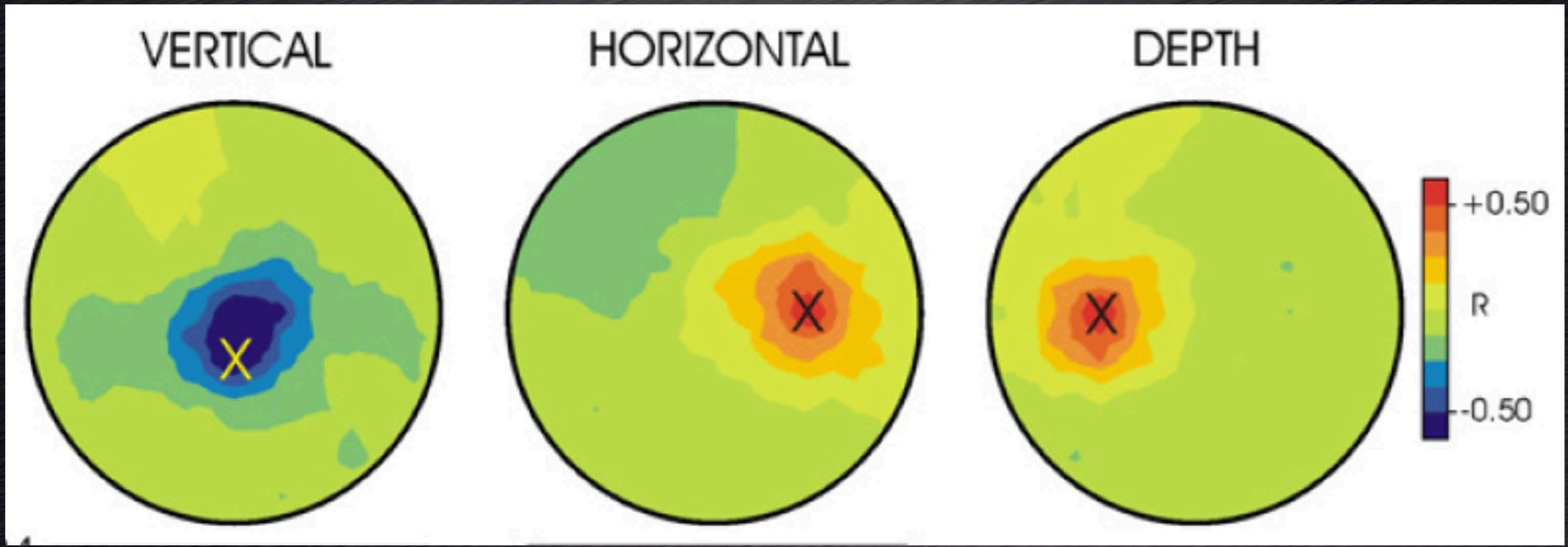
EEG Sensorimotor Rhythm (SMR) Control: Spectral & Topographical Focus





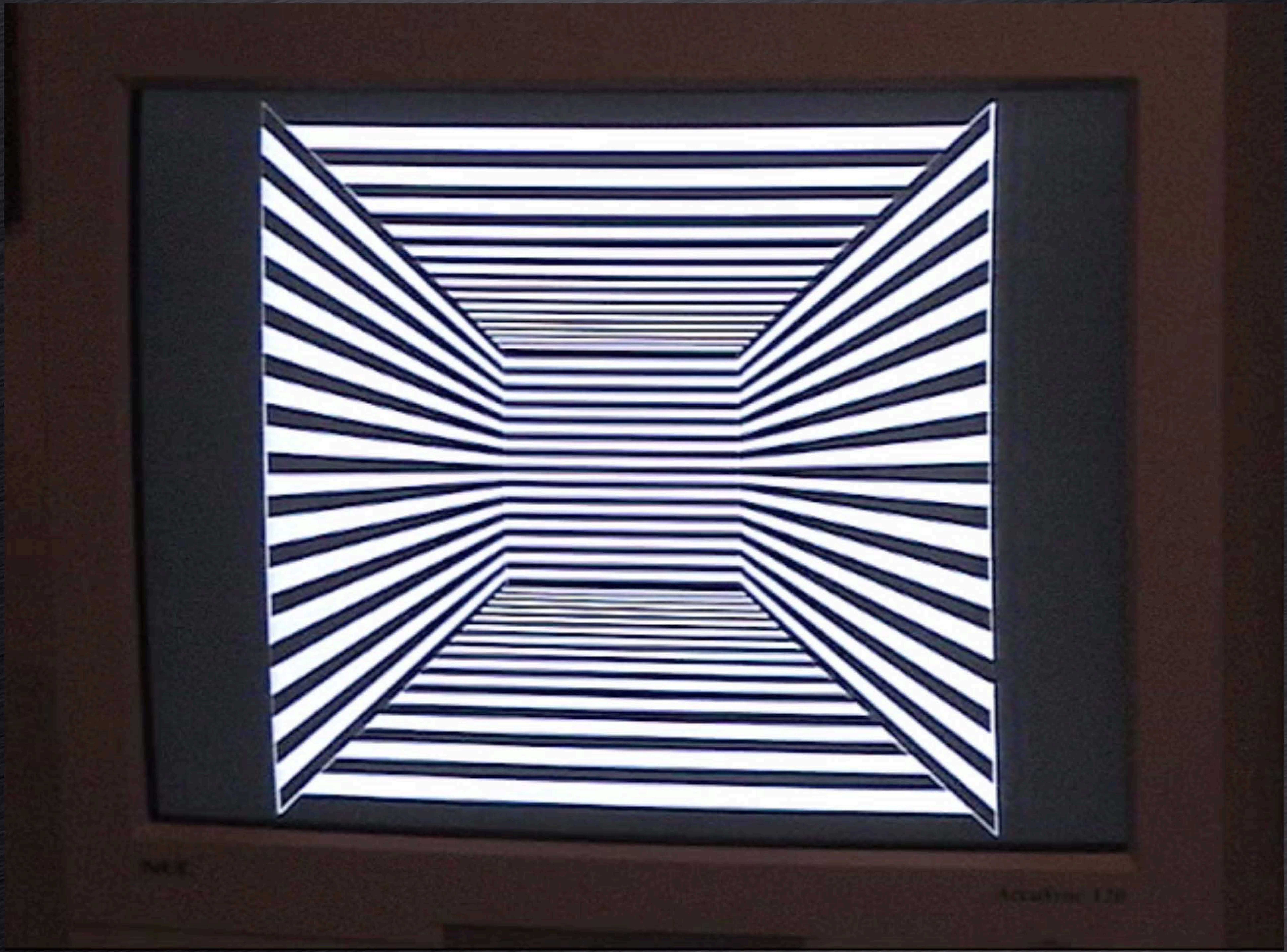
Wolpaw/McFarland et al, Pfurtscheller et al, Kostov/Pollack, Penny et al

Simultaneous Independent Channels of SMR Control



McFarland et al. JNE 2010

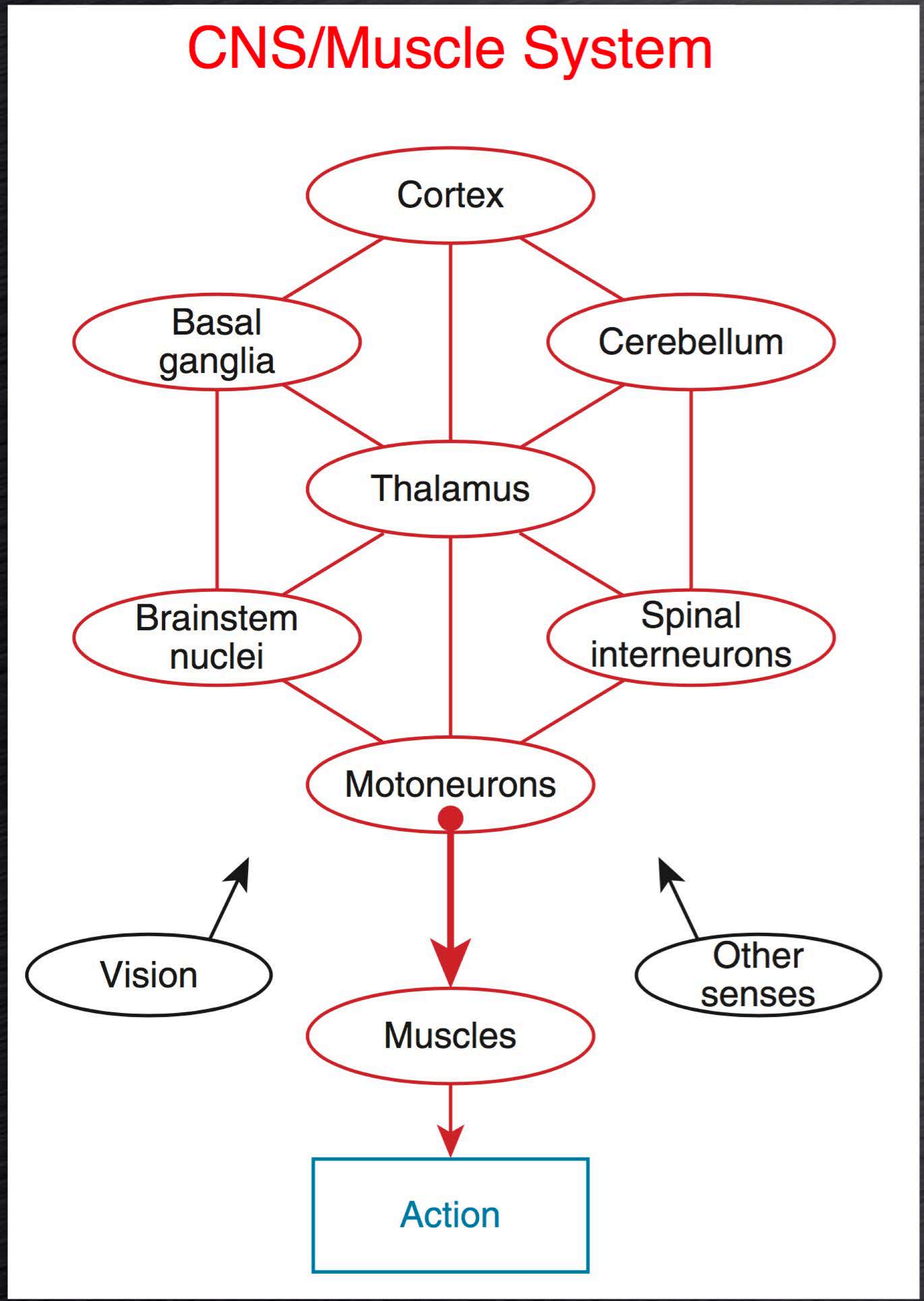
Three-Dimensional Movement Control with SMRs

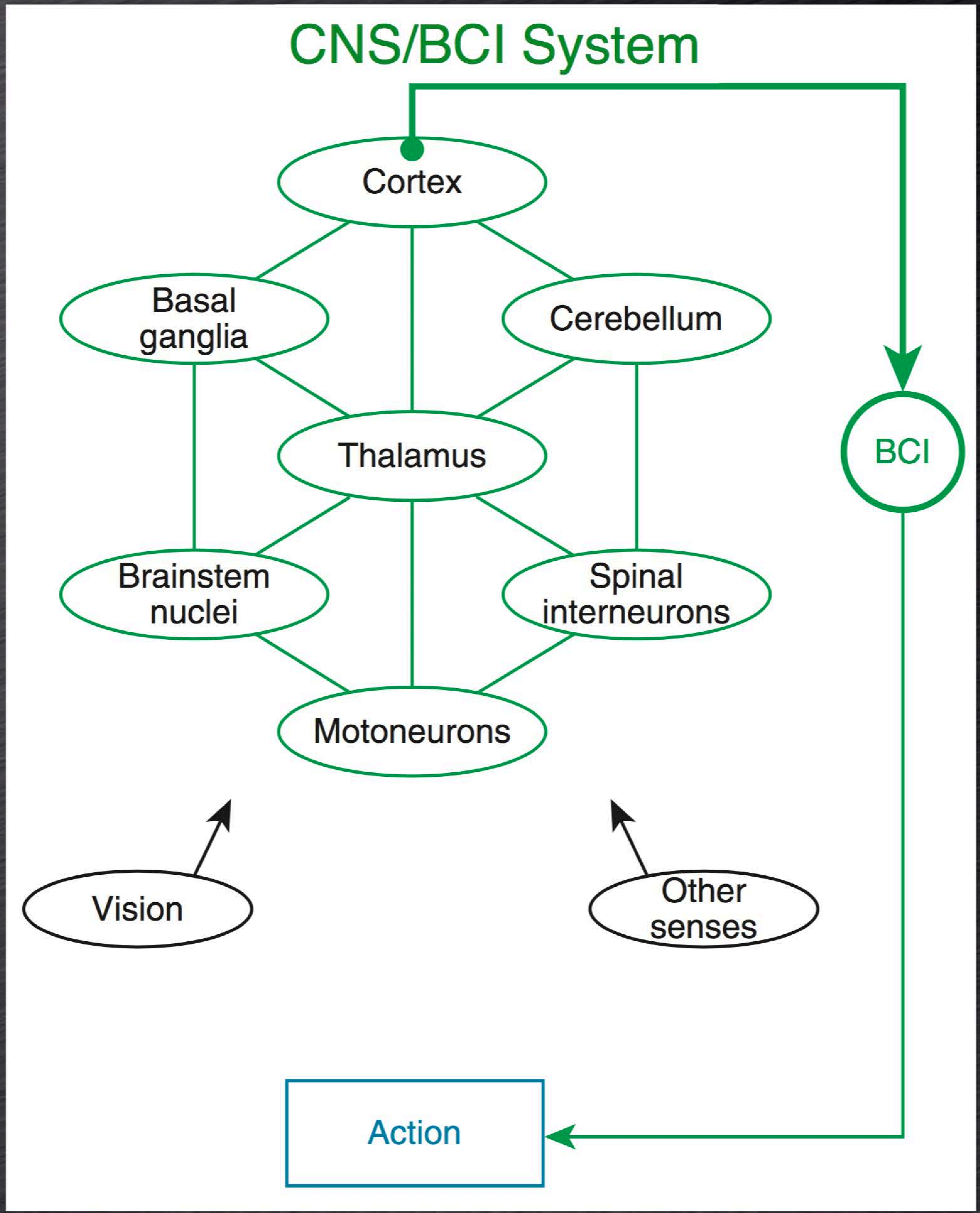


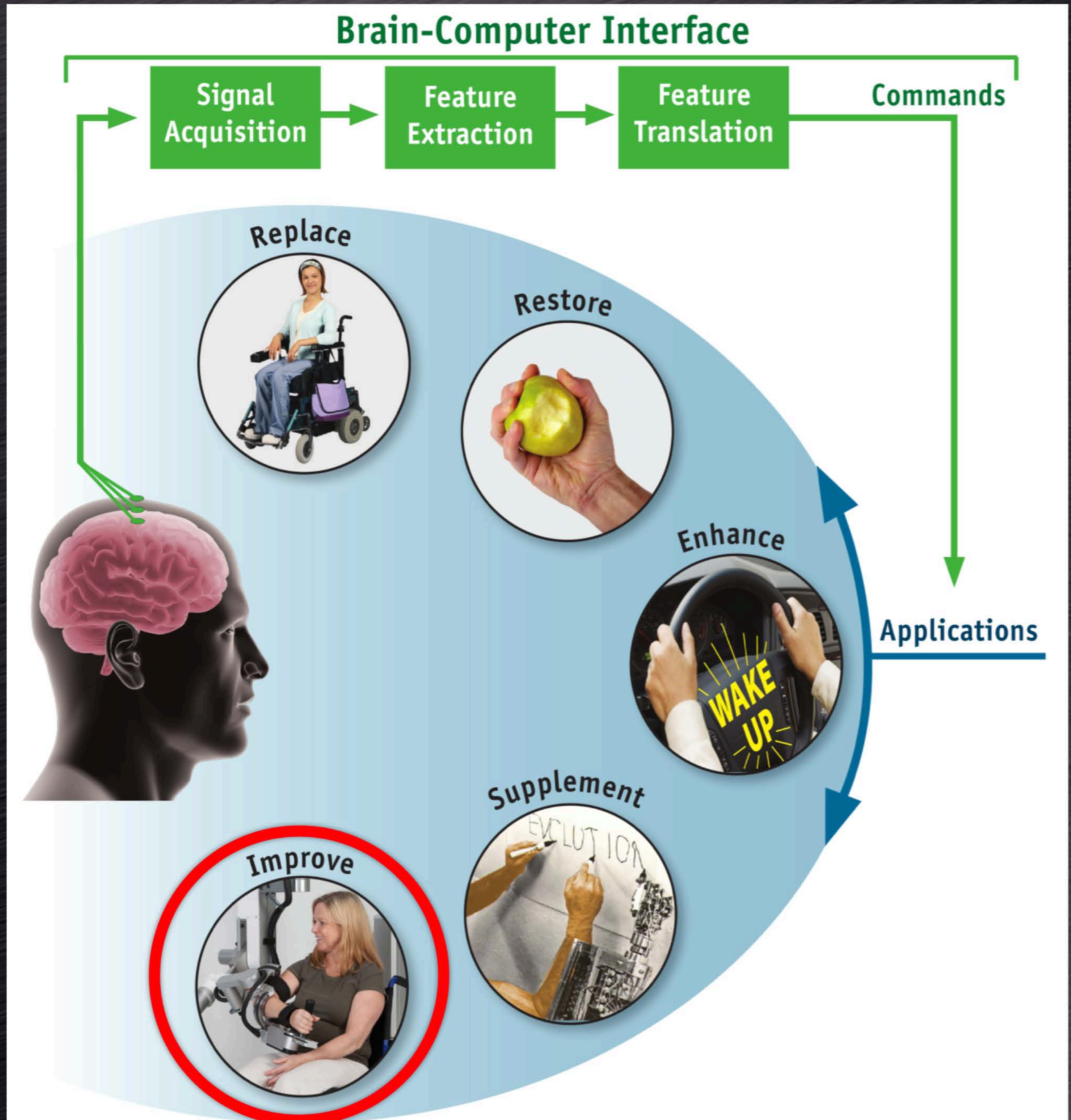
McFarland et al, JNE 2010

The Grand Canyon Problem

Primary Origin of the Grand Canyon Problem






Brain-Computer Interface
Signal Acquisition
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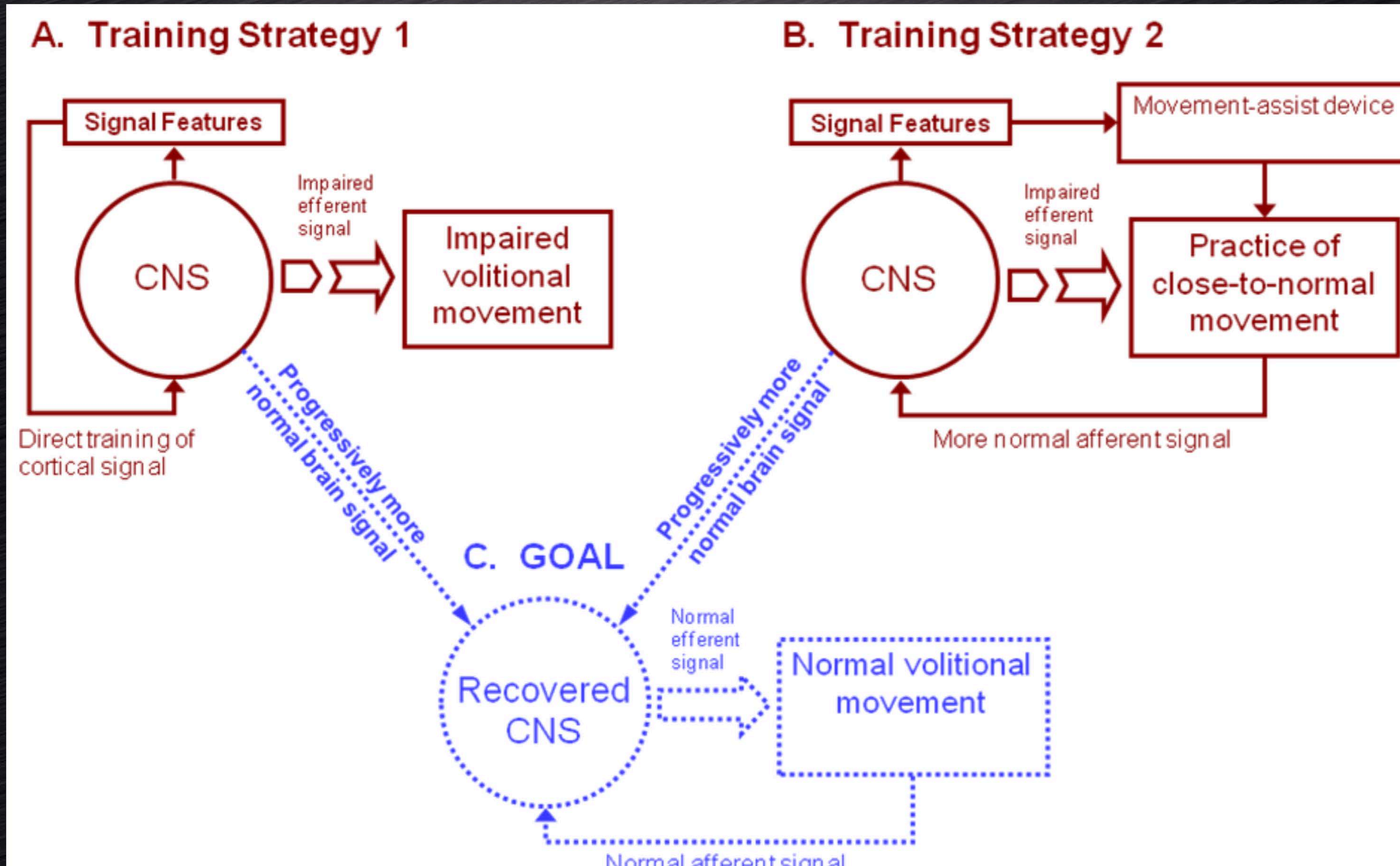
Improve

BCI-based Rehabilitation



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Daly & Wolpaw, Lancet Neurol 2008

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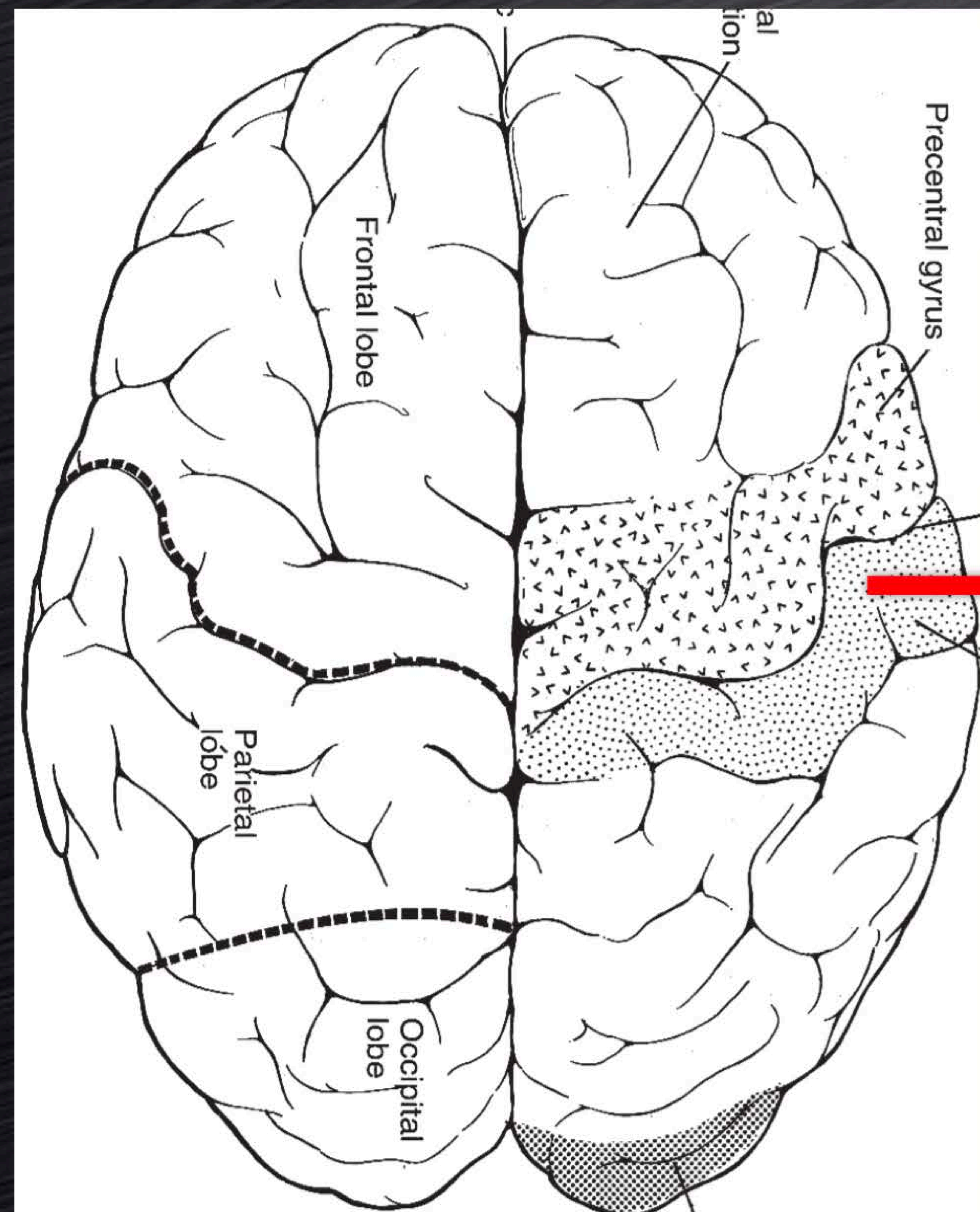
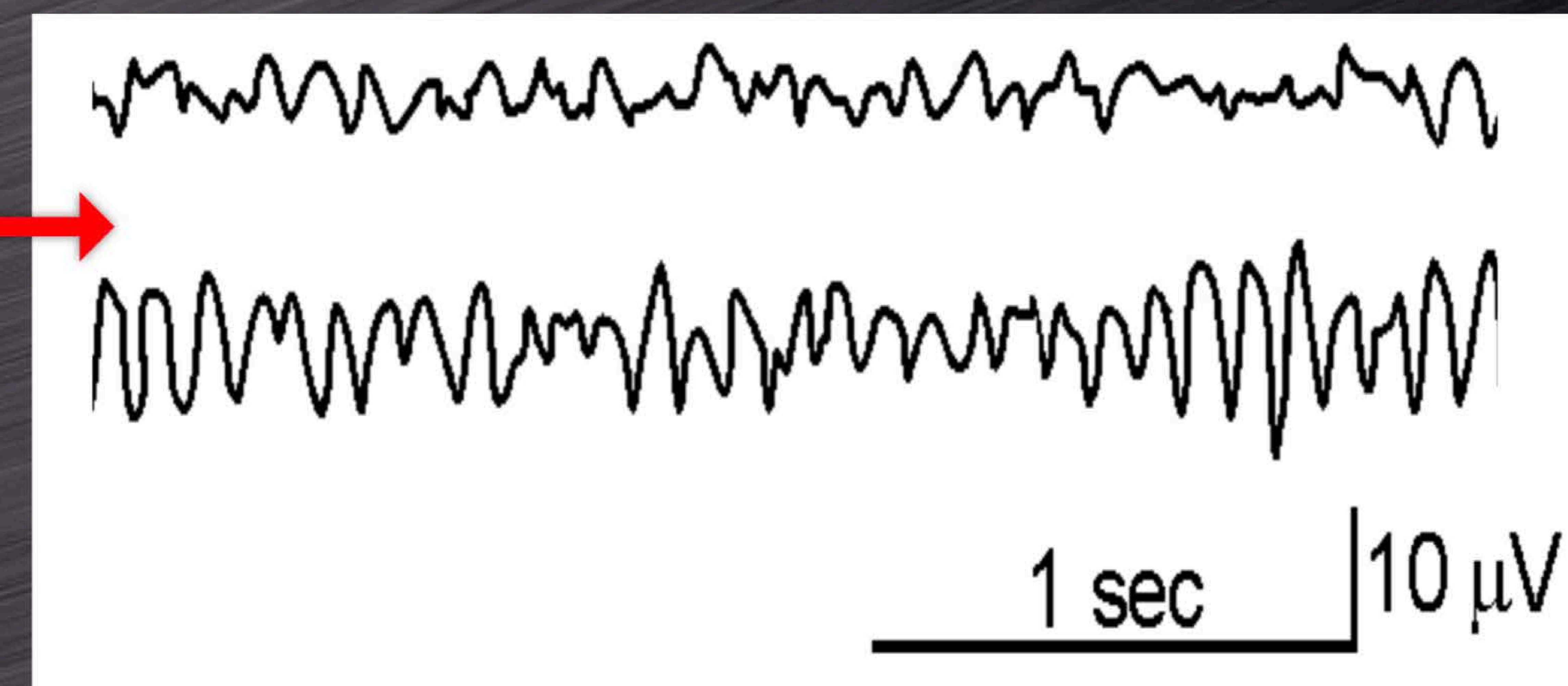
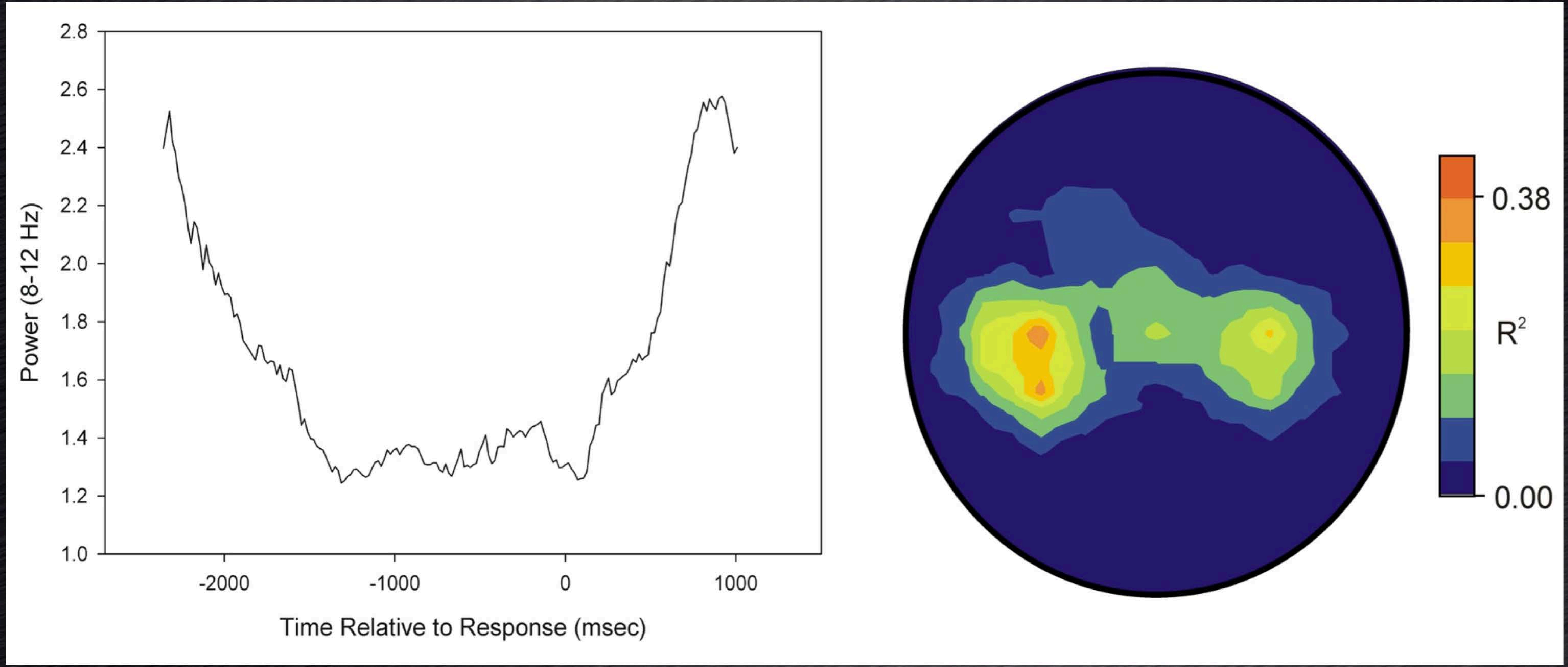
SMRs reflect the brain activity underlying movement





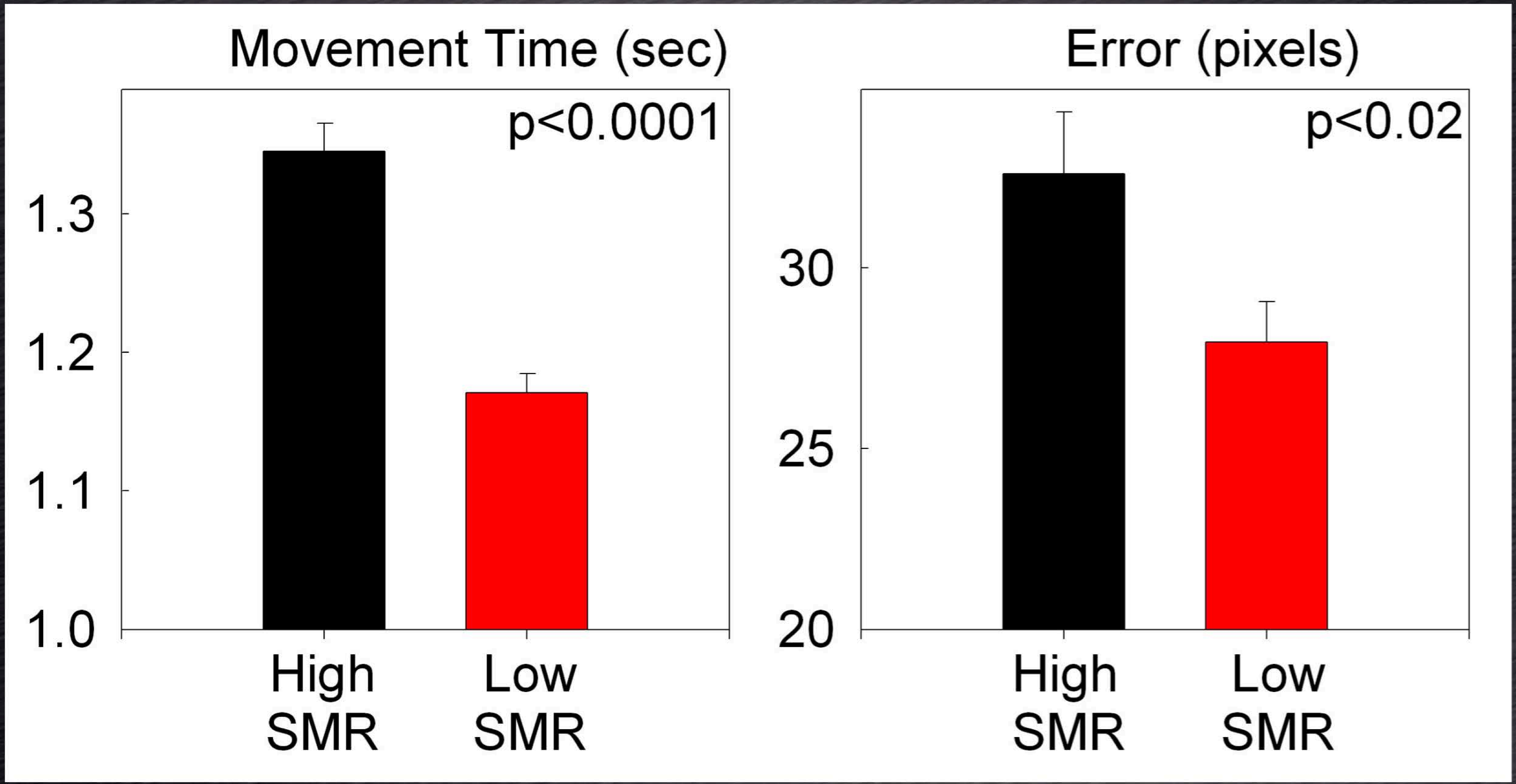
McFarland et al. 2013

SMRs reflect the brain activity underlying movement



McFarland et al. 2013

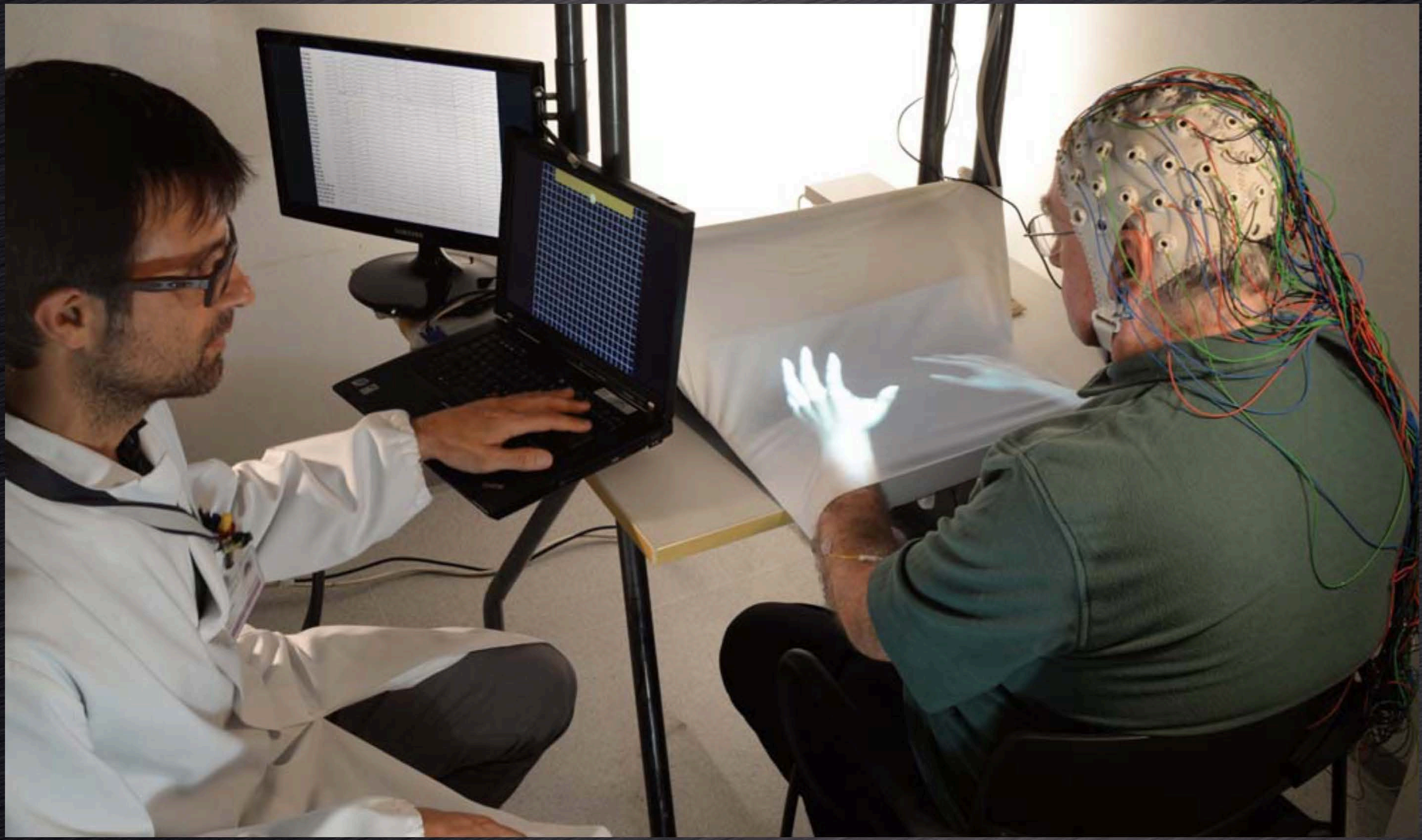
SMRs reflect the brain activity underlying movement



Modifying them might improve impaired movement

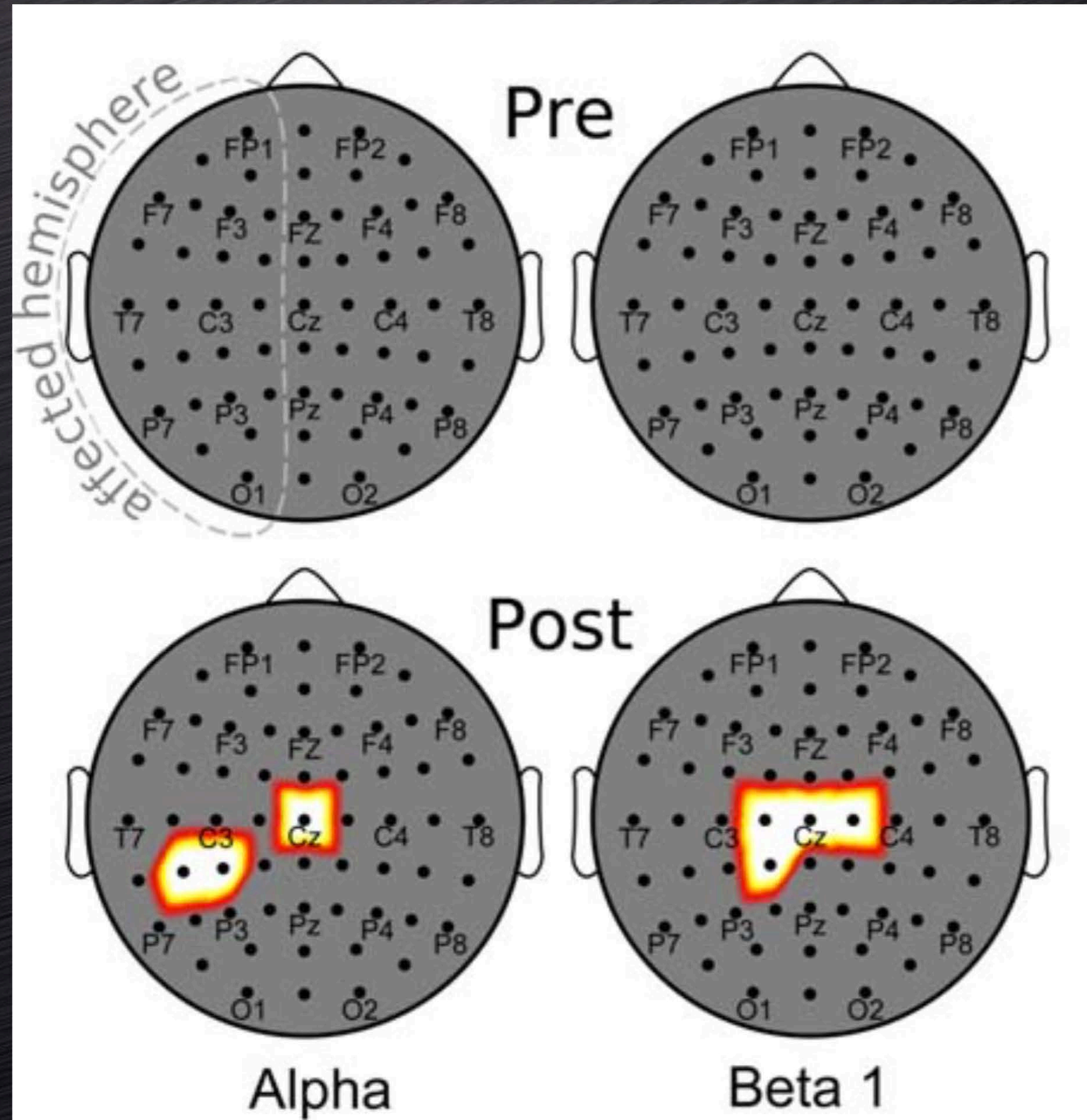
McFarland et al. 2013

Brain–Computer Interface Boosts Motor Imagery Practice during Stroke Recovery



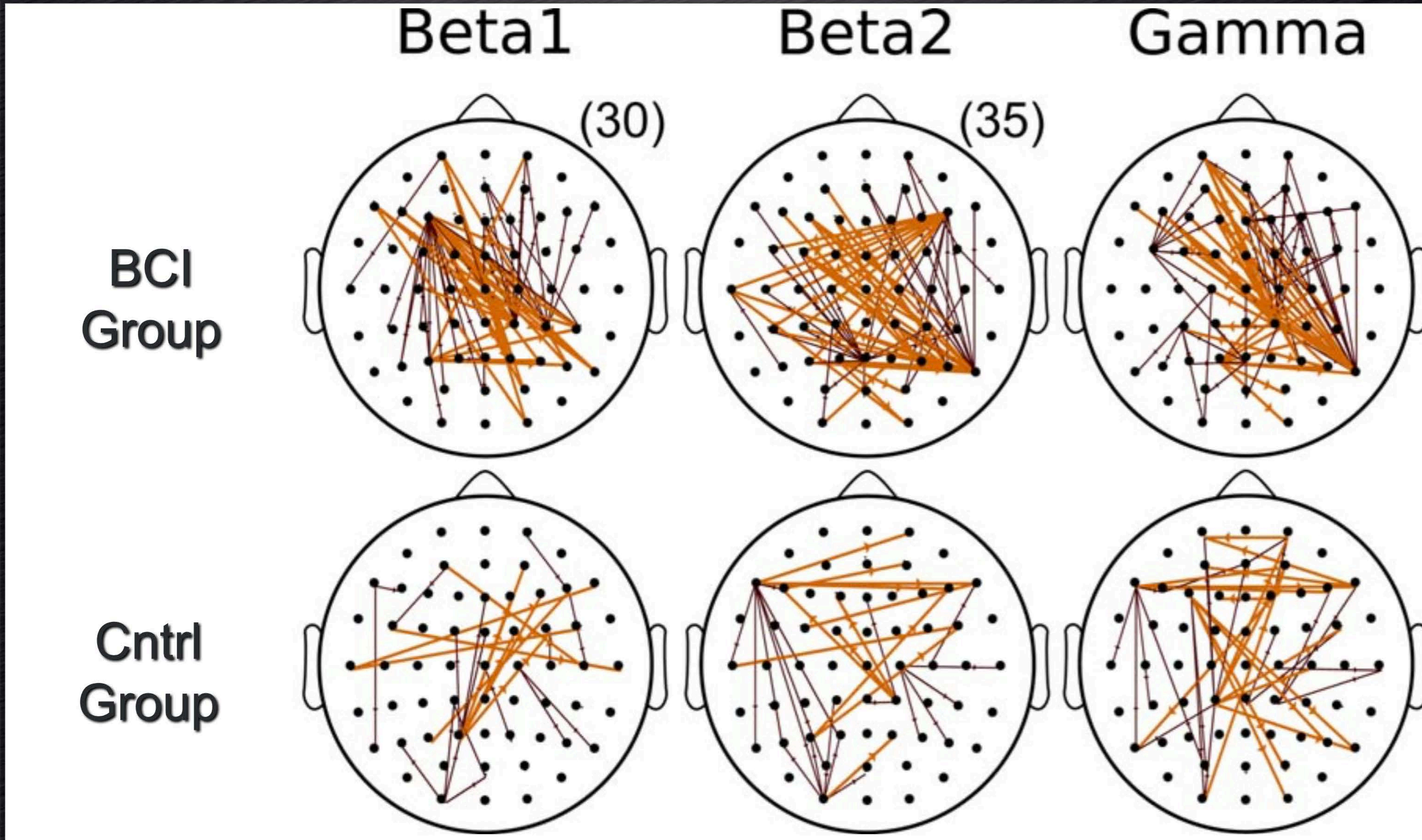
Pichiorri et al. Ann Neurol 2015

BCI-based Stroke Rehabilitation



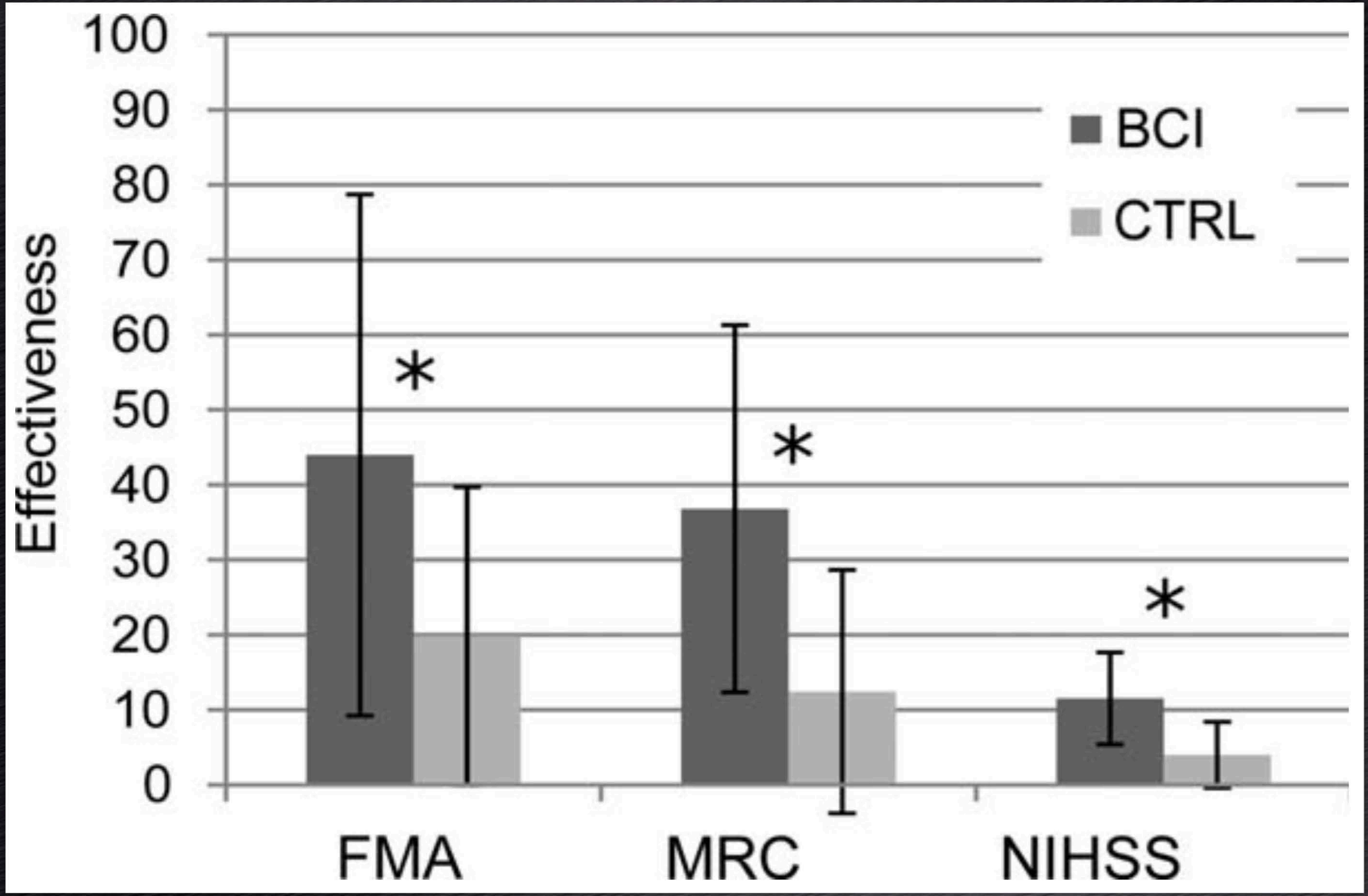
Pichiorri et al. Ann Neurol 2015

BCI-based Stroke Rehabilitation



Pichiorri et al. Ann Neurol 2015

BCI-based Stroke Rehabilitation



Pichiorri et al. Ann Neurol 2015

Using electrocorticography (ECoG) to localize cortical function before surgery

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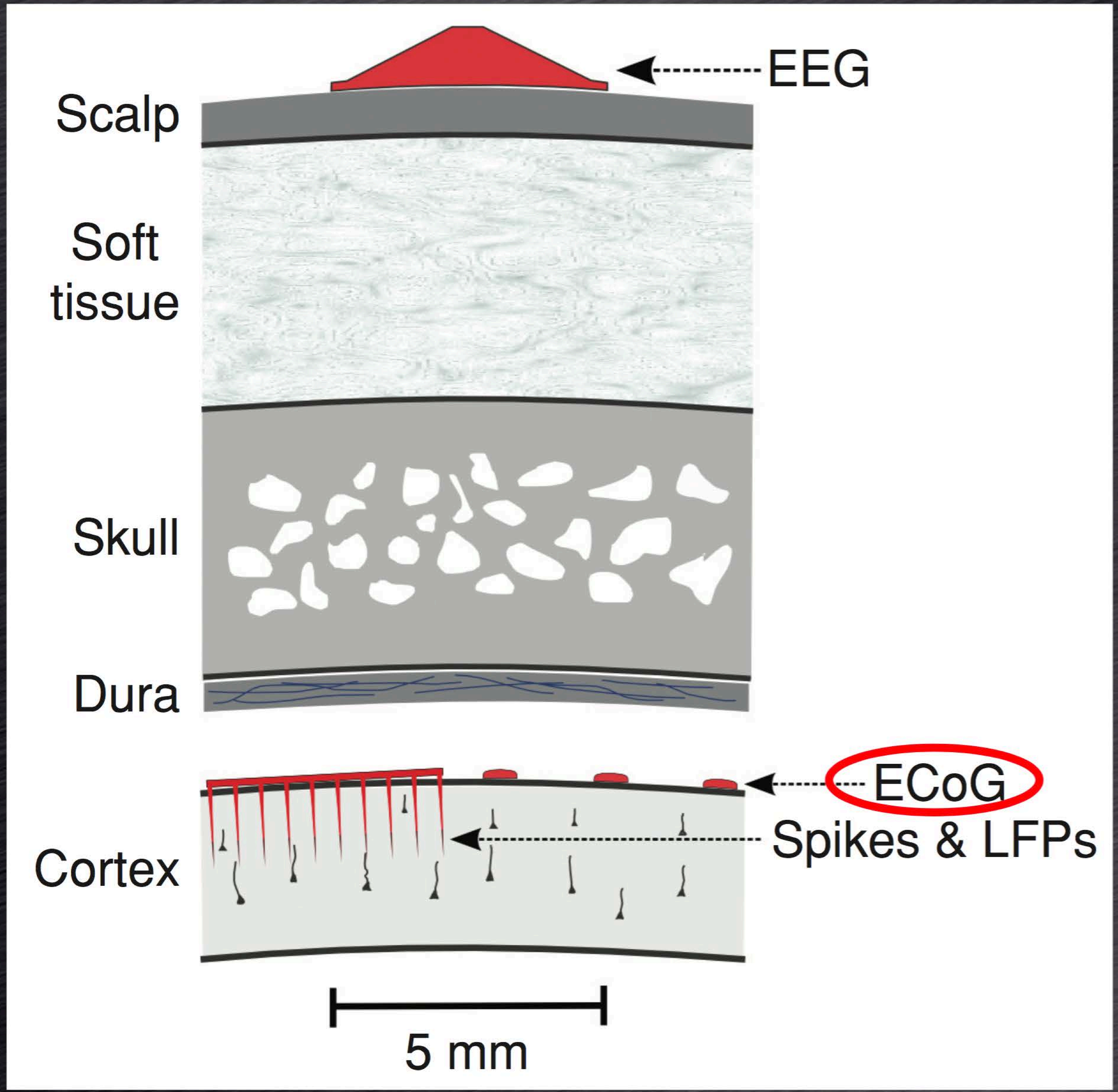
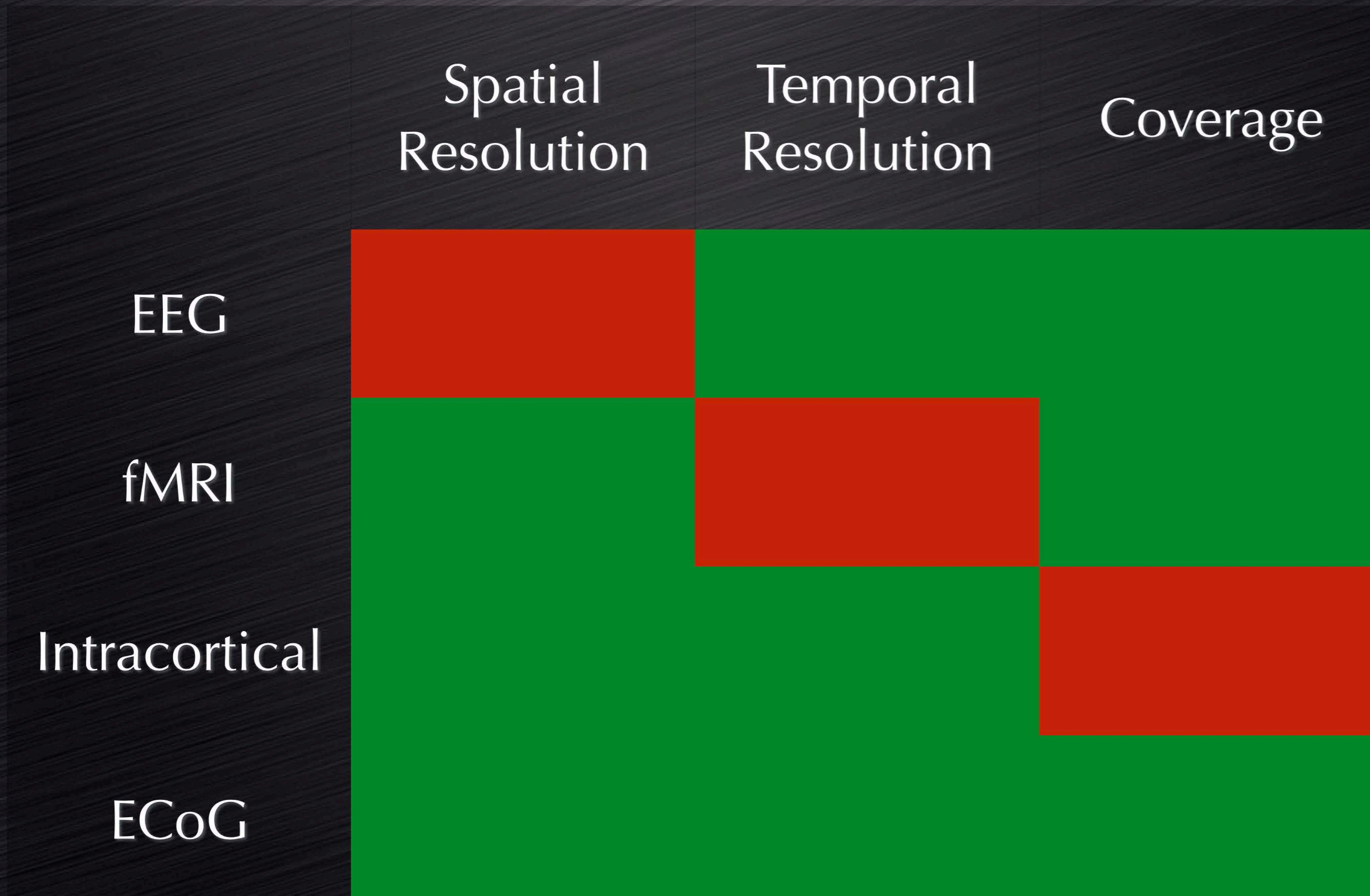
Electrophysiological Imaging of Brain Activity



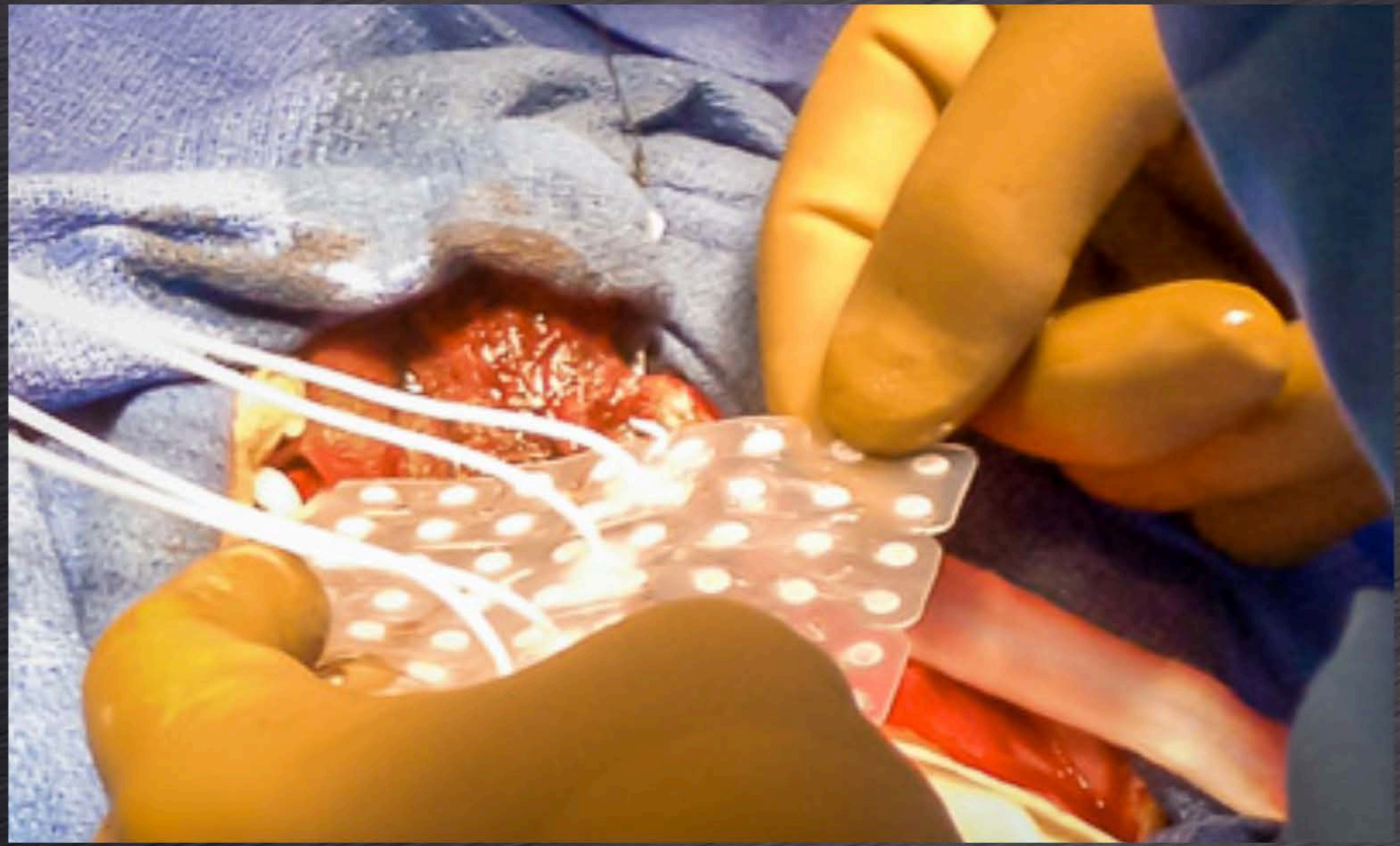
Wolpaw & Wolpaw, Oxford Univ Press, 2012

Imaging Brain Processes: Requirements



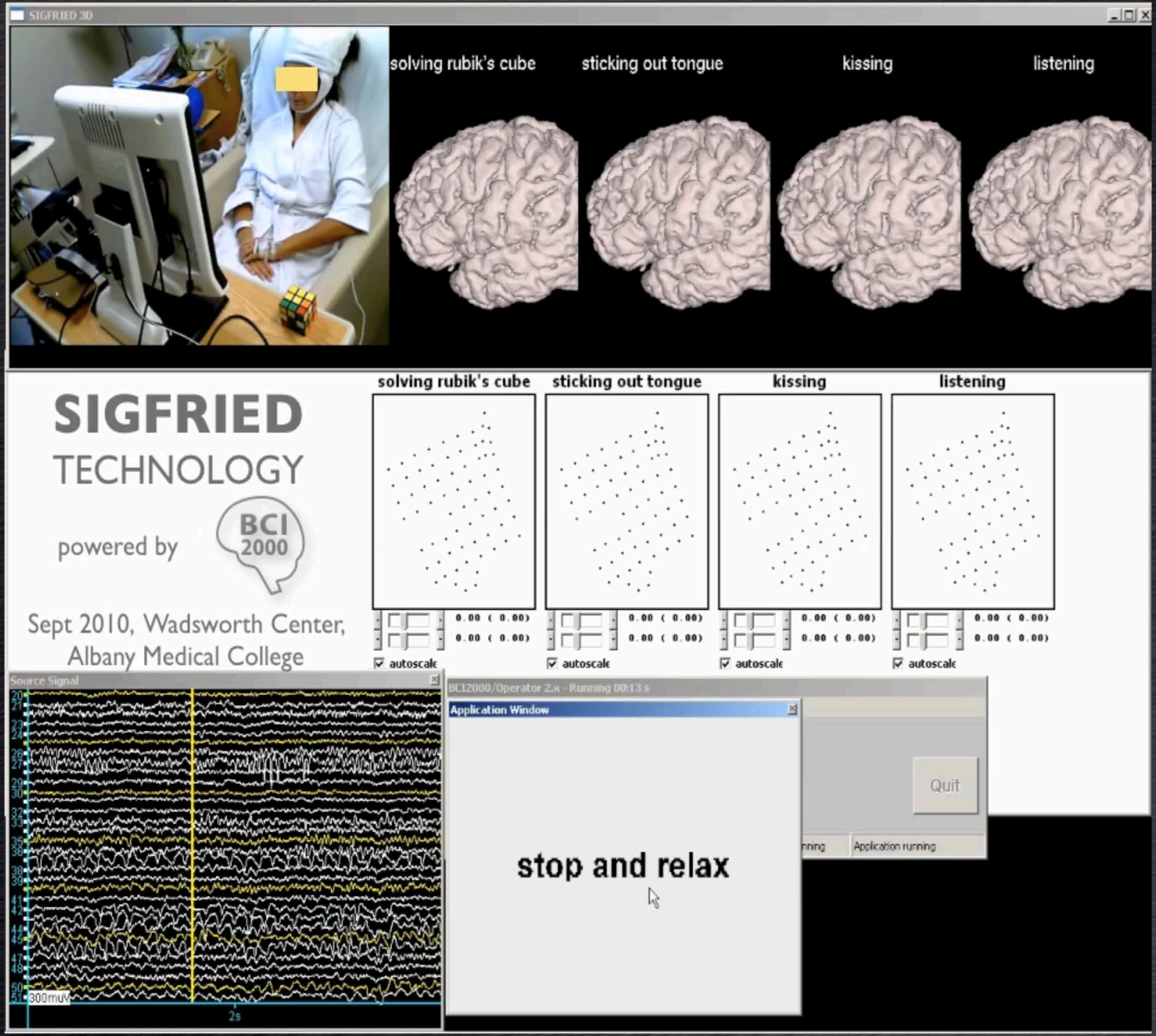
ECoG-based Functional Mapping prior to Surgery

- Epilepsy surgery often requires functional mapping



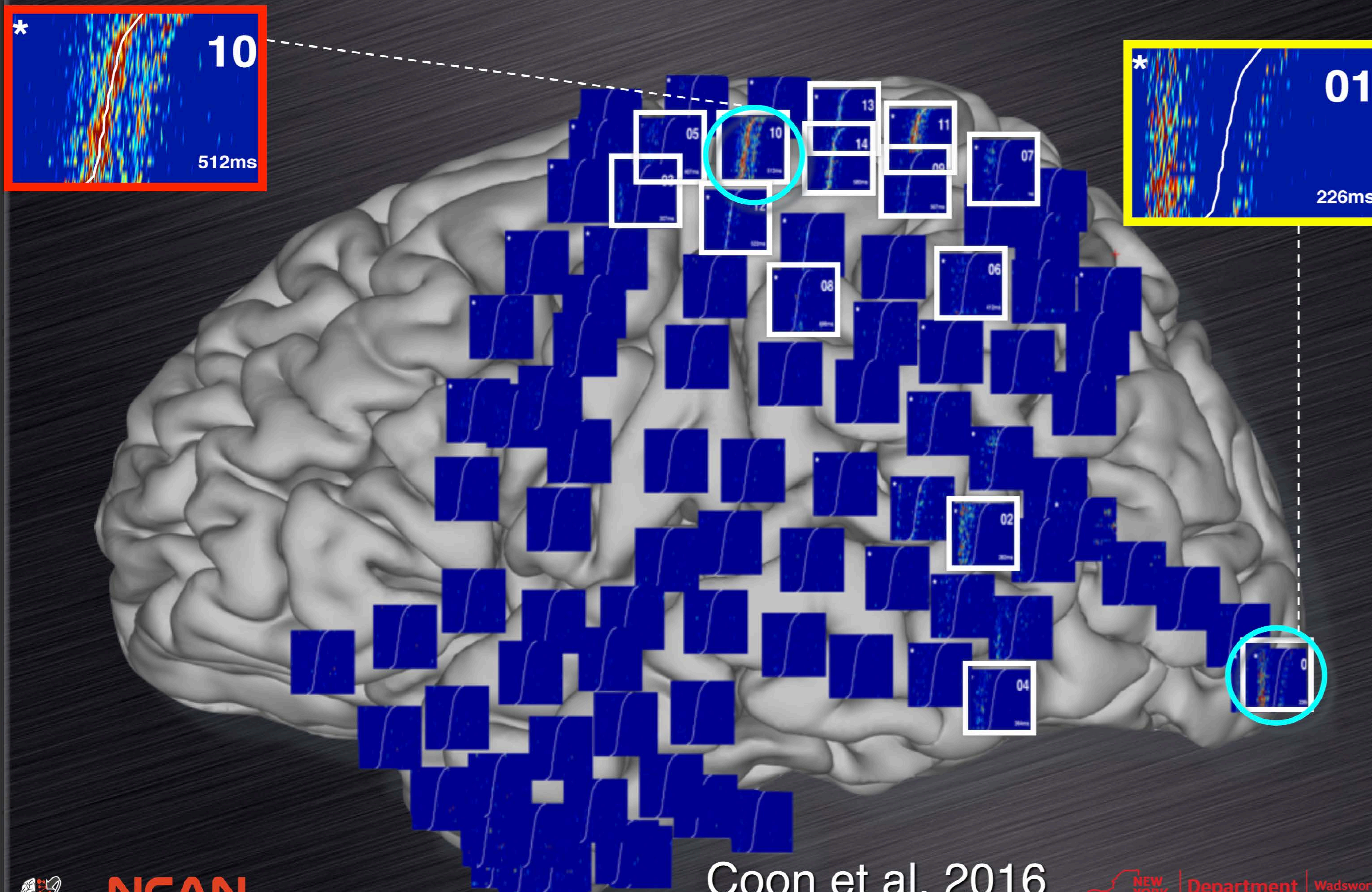
- Traditional stimulation method is time-consuming and risky
- ECoG-based passive mapping is a promising alternative
- New mapping method (SIGFRIED; Schalk et al. 2008)

Real-Time Functional Imaging



Brunner et al, Epil & Behav, 2009

The Sequential Activity Underlying a Behavior



Coon et al. 2016

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Reflex conditioning for rehabilitation after spinal cord injury:

Targeted Neuroplasticity

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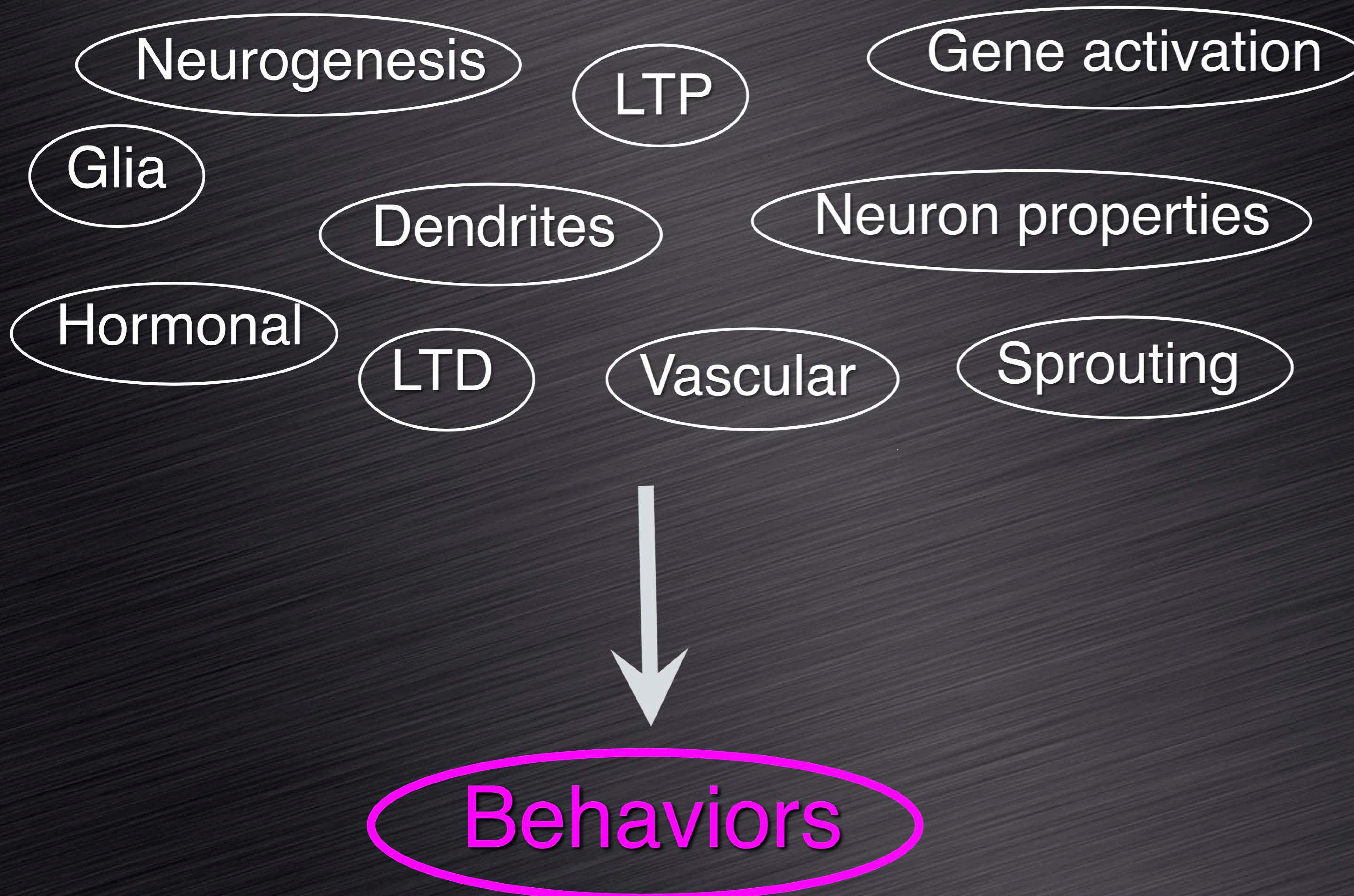
Traditional Rehabilitation

- Starts from the assumption that the CNS is largely hard-wired with little capacity for plasticity
- Tries to maximize remaining capacities and to induce whatever minimal plasticity is possible
- Two major strategies
  - Practice impaired behaviors (e.g., locomotor training)
  - Drugs to reduce dysfunction (e.g., baclofen for spasticity)
- Often limited efficacy
  - Important behaviors are not fully restored
  - Significant side effects may occur

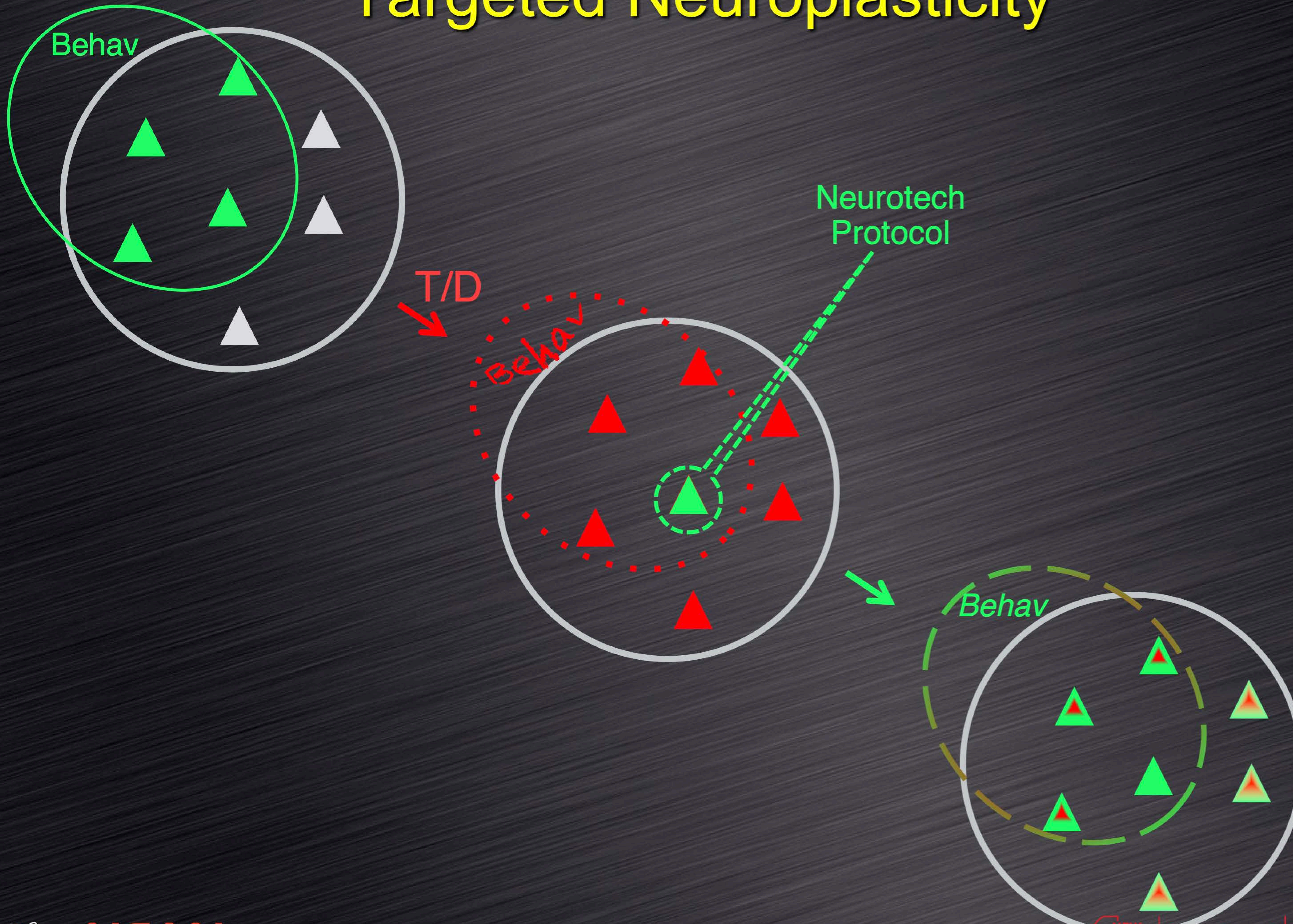
Plasticity is Ubiquitous and Continuous in the CNS



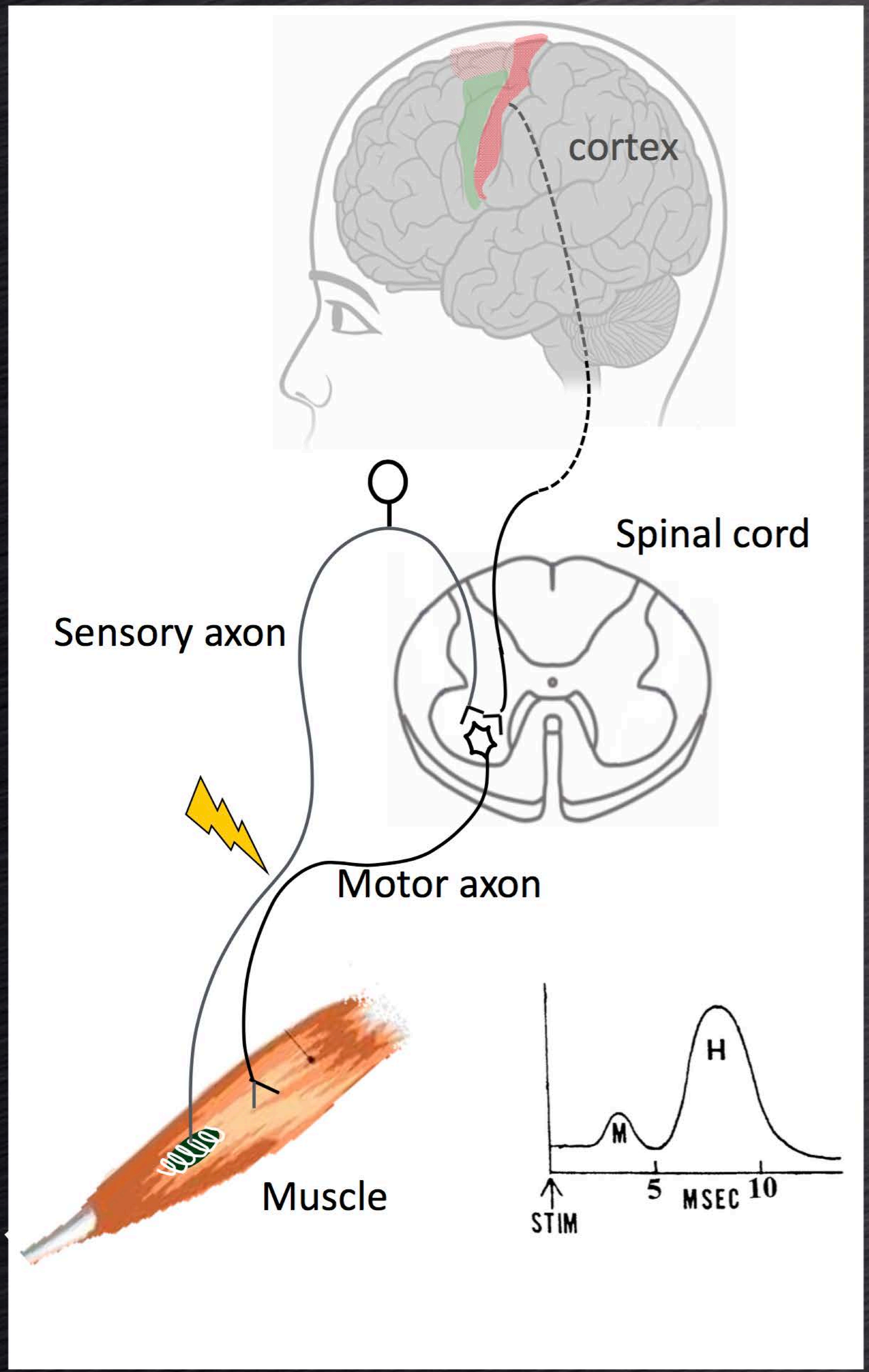
Activity-Dependent Plasticity: Ubiquitous & Continuous in the CNS

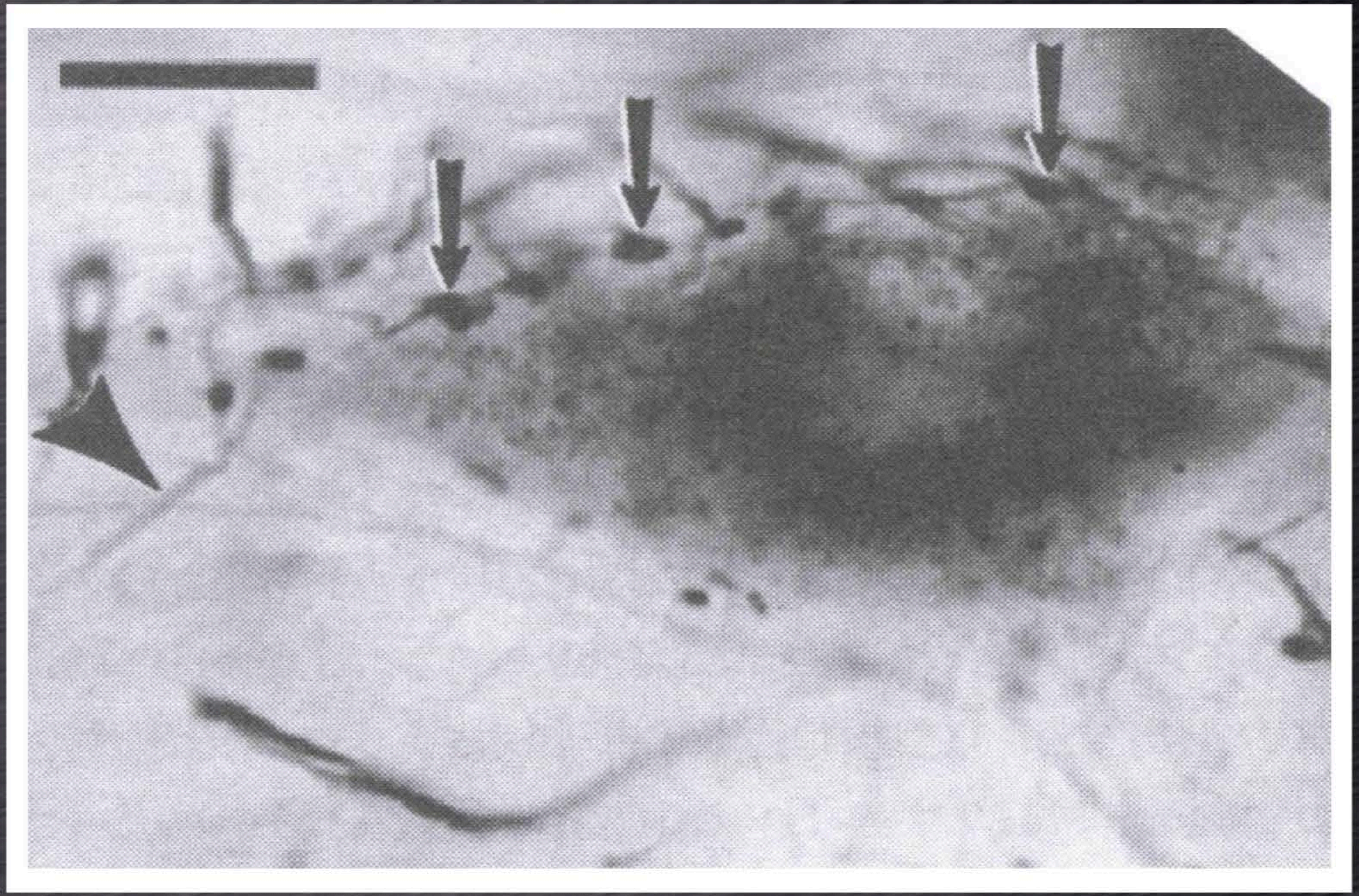
- Many mechanisms; $>>10^{12}$ sites; msec to years
- Thus, when function is impaired there are many options
- No direct overall guidance
- The drivers are local; most sites are far from behavior
- Thus, no certainty that optimal pattern of plasticity will occur
- Traditional rehab is not specific, does not target specific sites; seldom fully effective
- New methods are needed

Targeted Neuroplasticity



Targeted Neuroplasticity: Modifying the H-Reflex

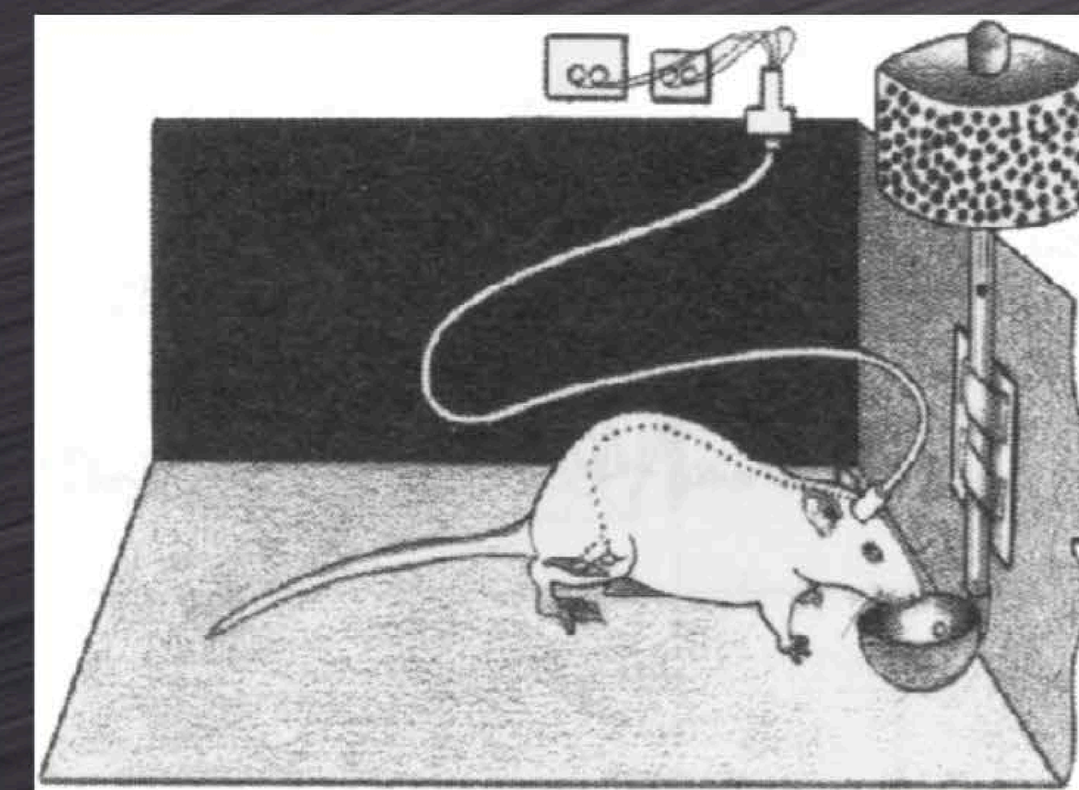




Monkeys, rats, mice, and people can gradually change H-reflex size when rewarded for doing so.

Operant Conditioning of Spinal Reflexes 1978-2017

Monkey stretch reflex
1983



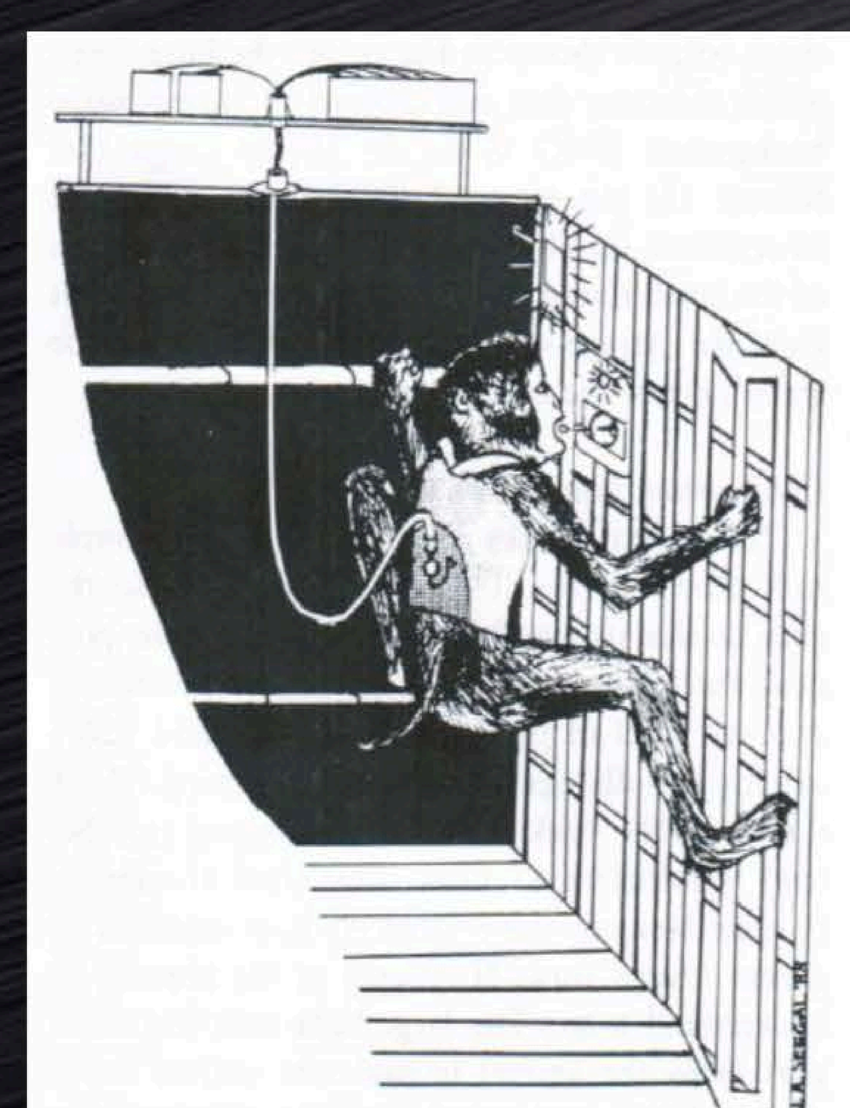
Rat H-reflex
1995

Rats with SCI
2006

People with SCI
2013

MODEL DEVELOPMENT ⟶ *MECHANISTIC STUDIES* ⟶ *THERAPEUTIC APPLICATIONS*

1987
Monkey H-reflex



2005
Mouse H-reflex

2009
Human H-reflex

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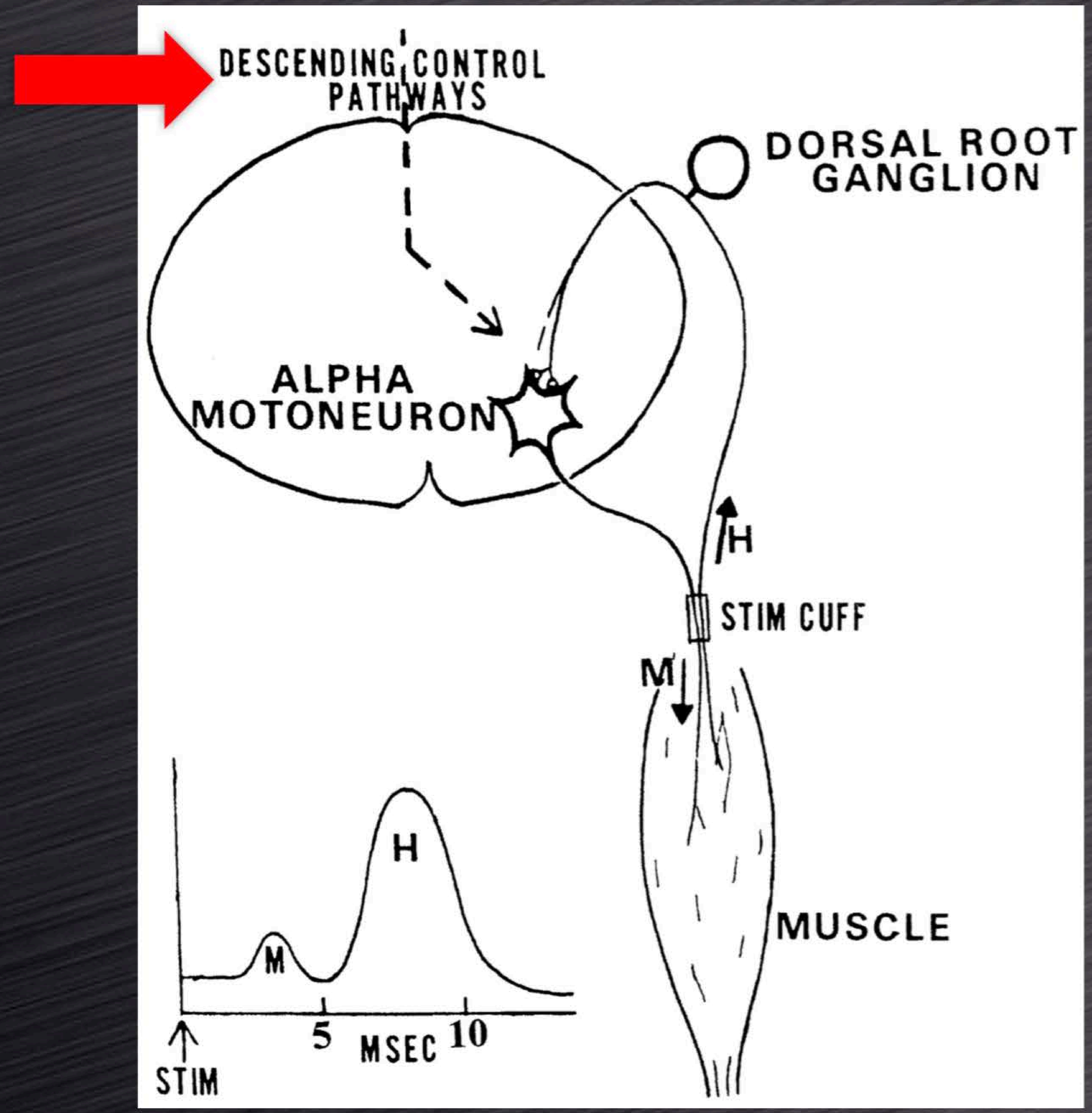
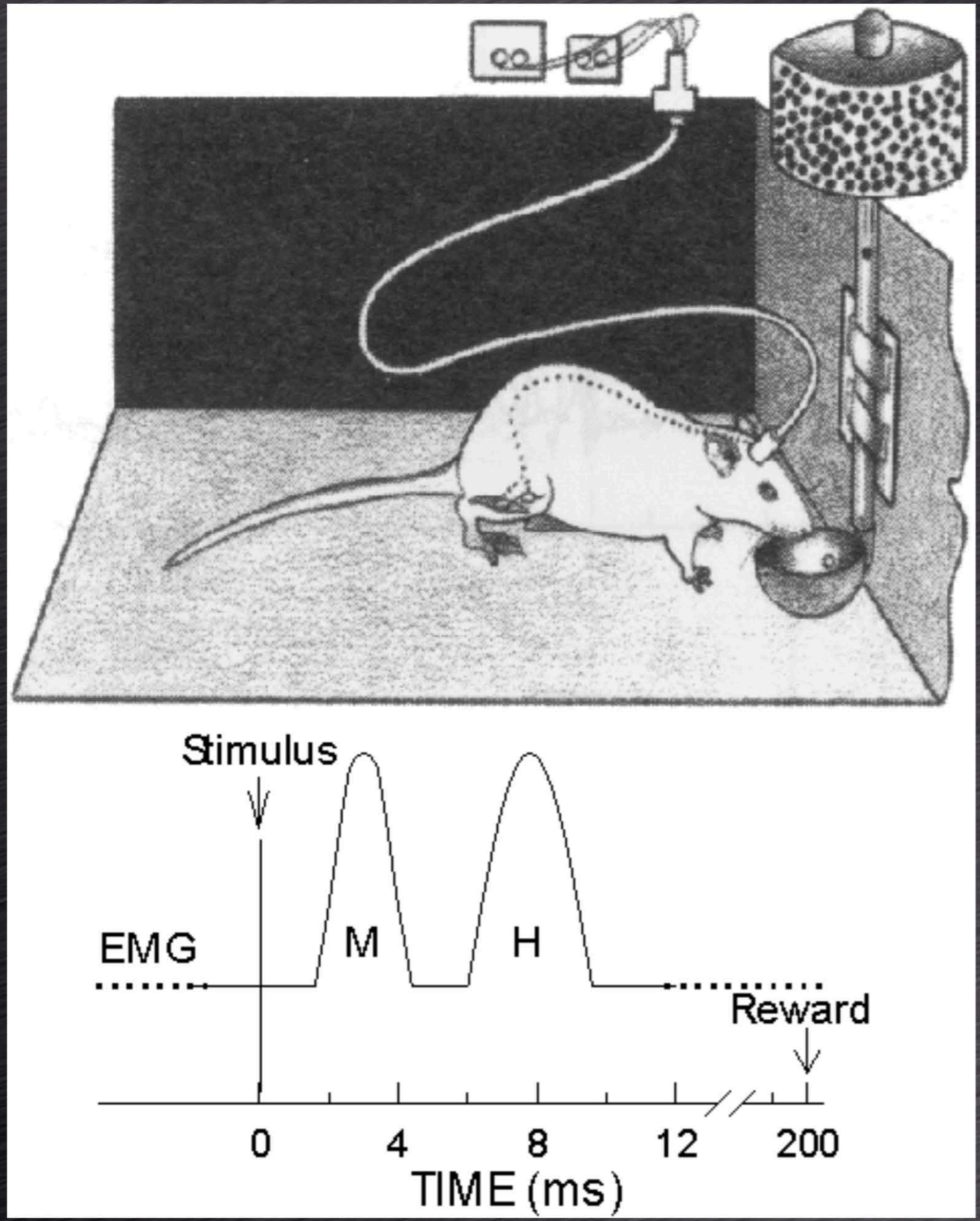
Operant Conditioning

A subject is given a specific stimulus or placed in a specific situation, and reinforcement (reward) occurs when a specific response occurs. After repeated exposures to this experience, the required response occurs more frequently and thereby increases the number of rewards.

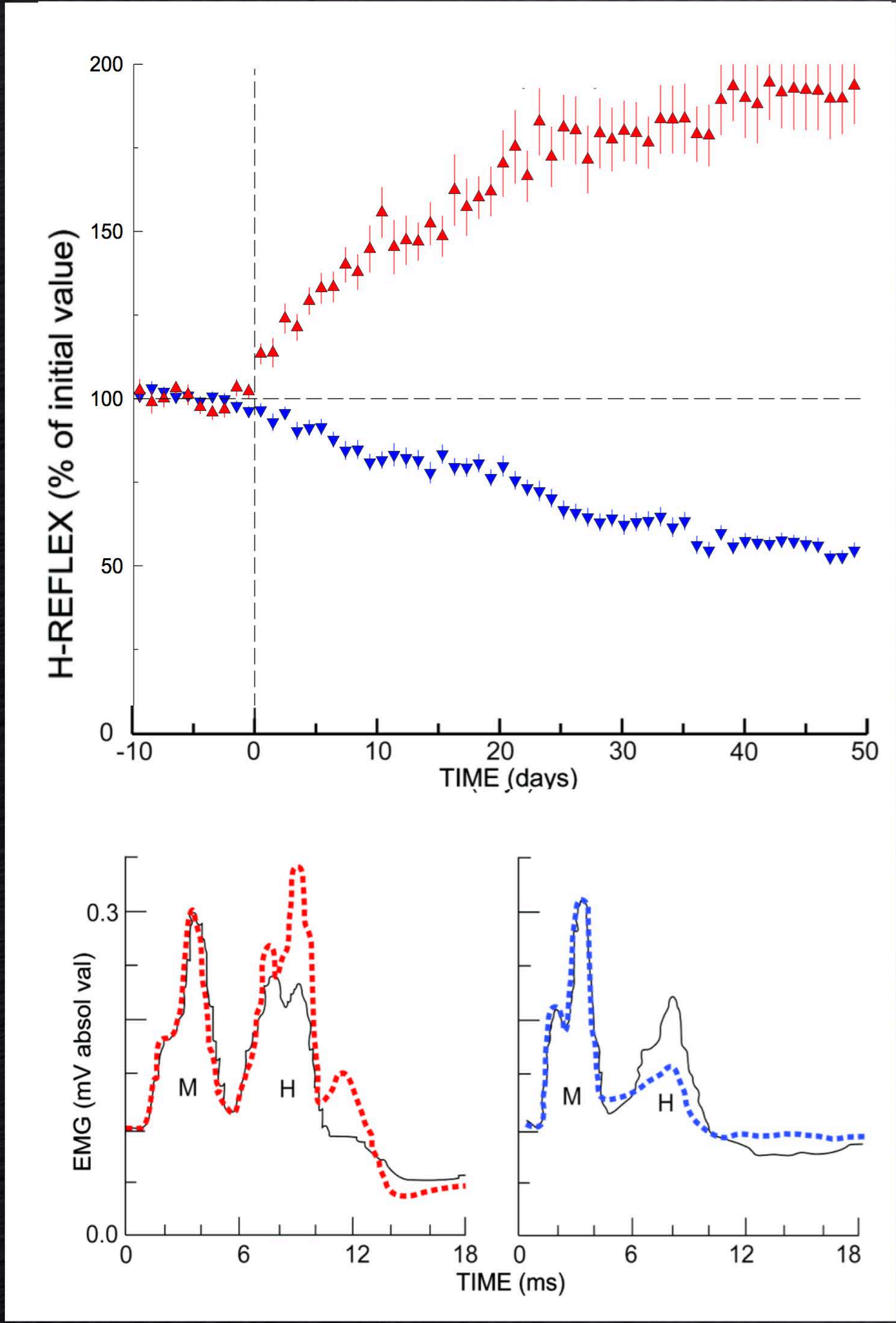


The Operant Conditioning Protocol



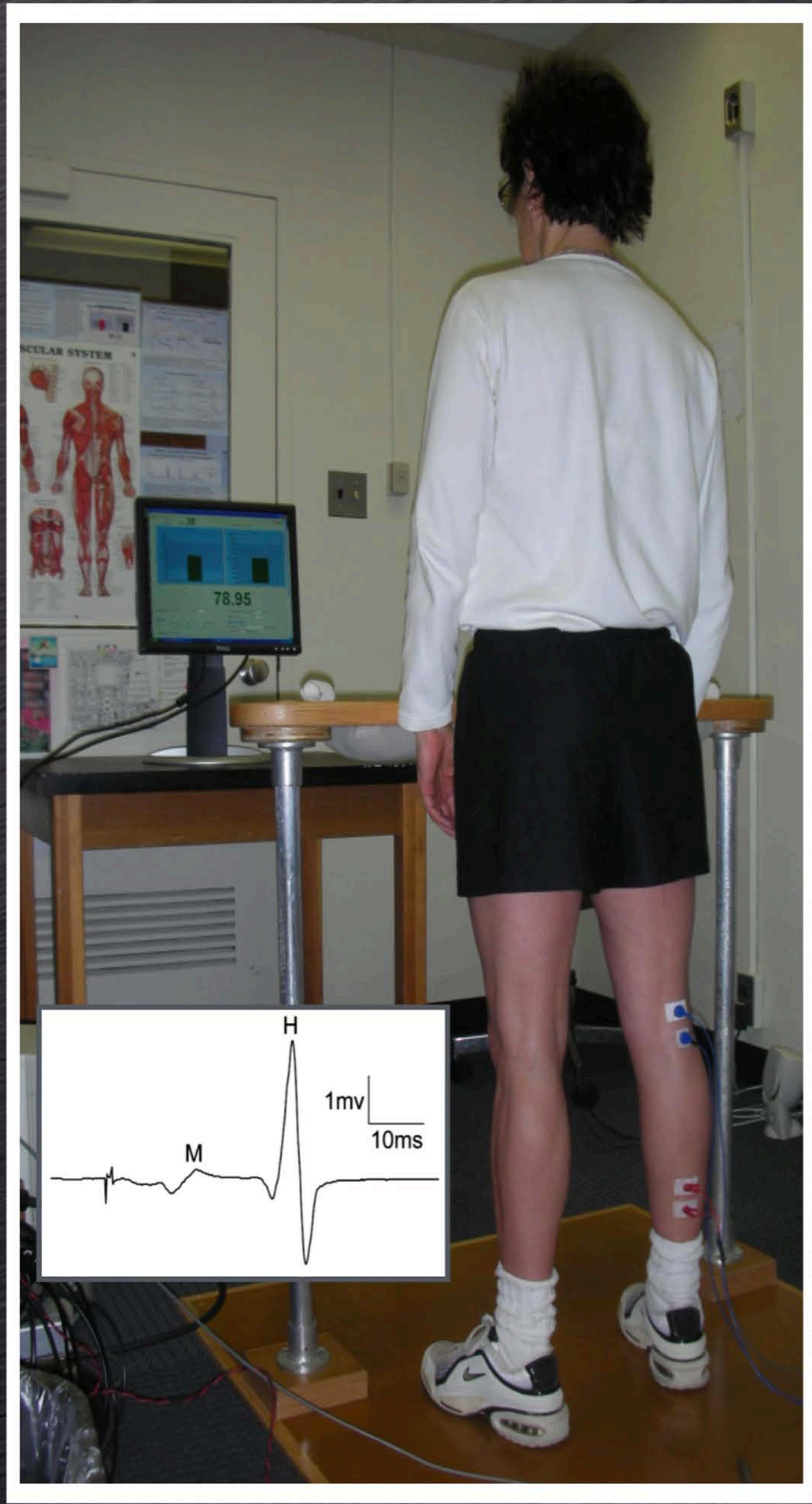
Wolpaw TINS 1997

H-Reflex Conditioning in Rats



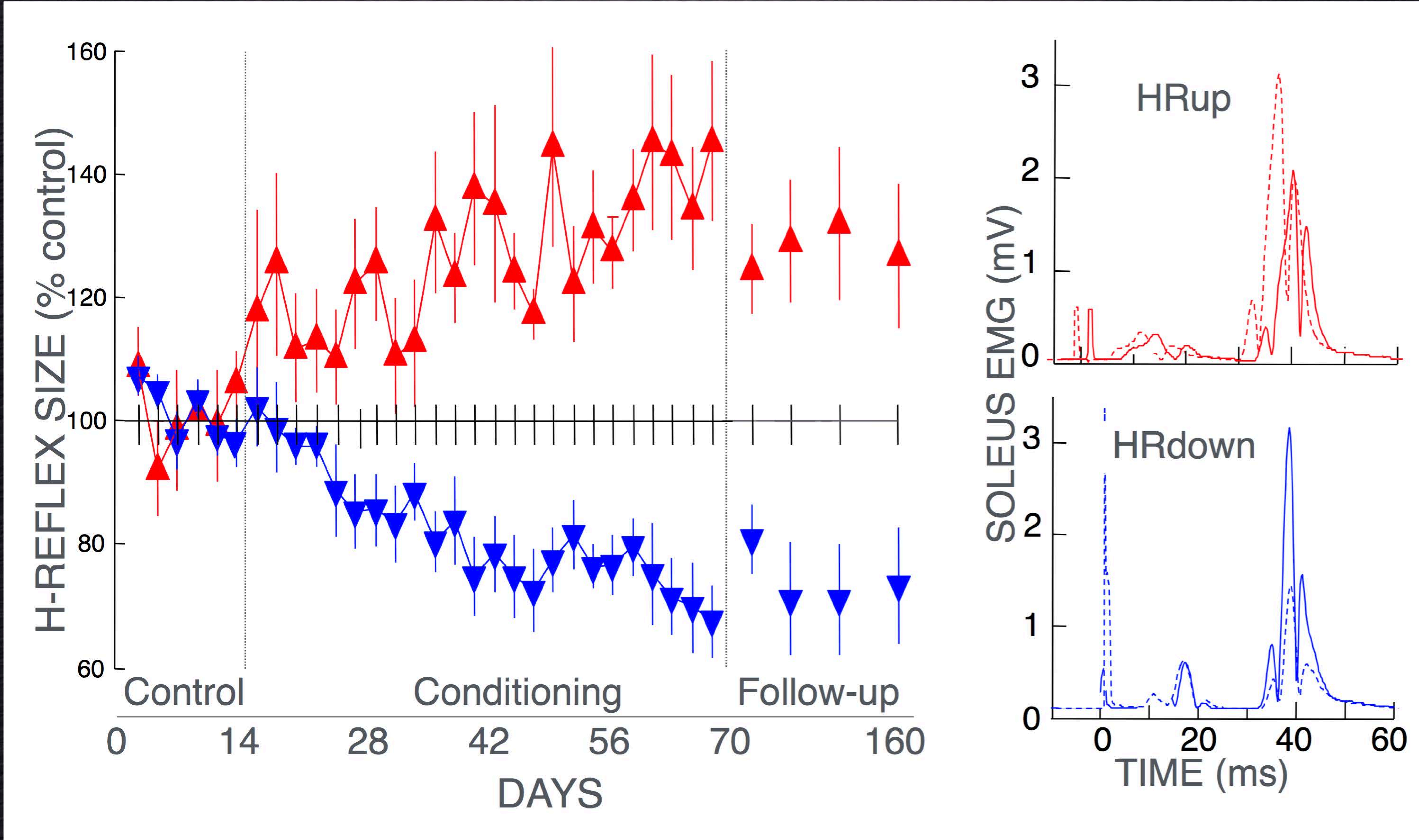
Wolpaw TINS 1997 + later data

H-Reflex Conditioning in People



Thompson et al. J Neurosci 2009

H-Reflex Conditioning in People



Thompson et al J Neurosci 2009

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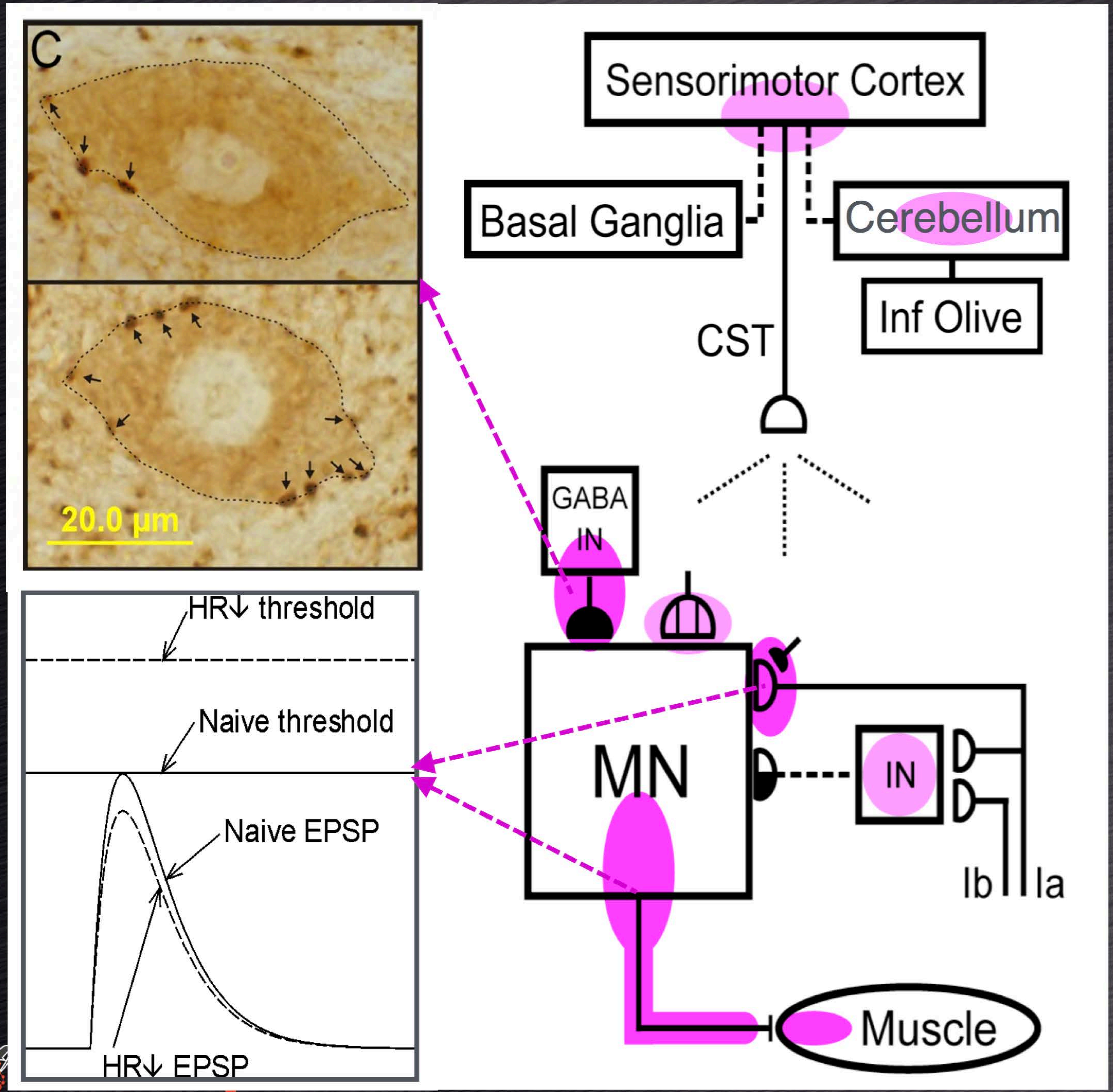
H-reflex conditioning creates a hierarchy of plasticity



Updated from Encyclopedia of Neuroscience, 2009

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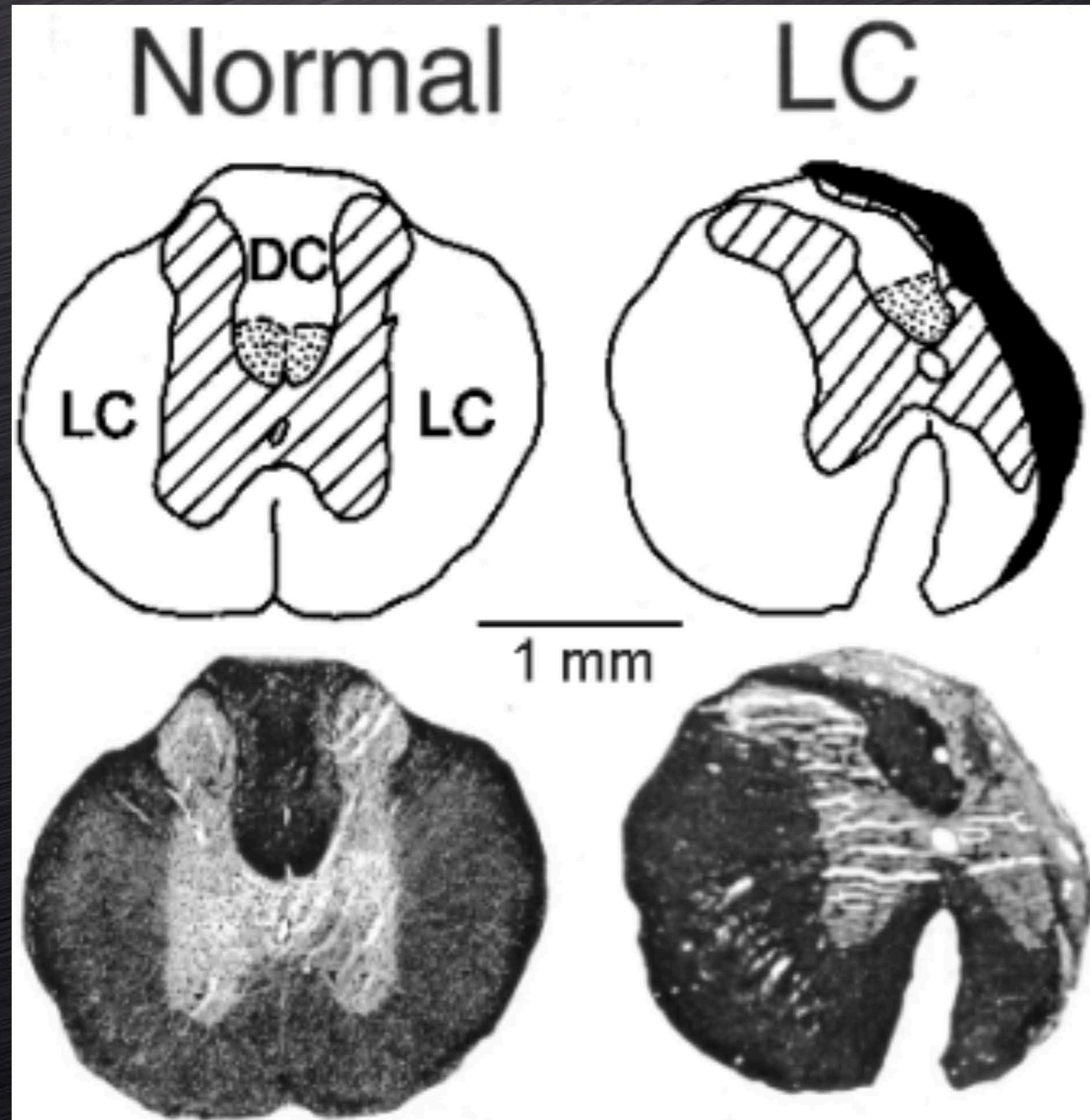
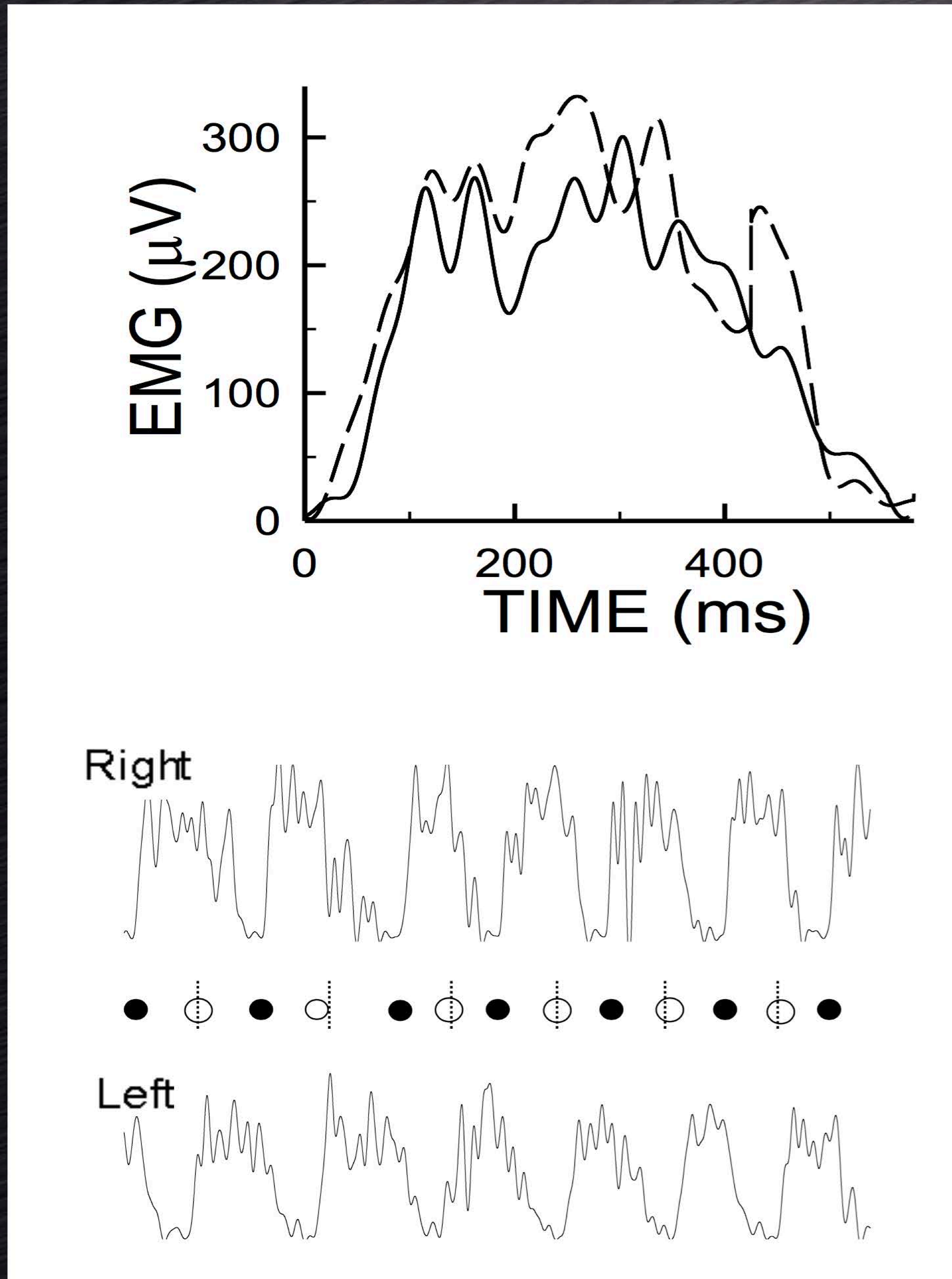
Spinal Cord Injury: T9-10 Lateral Column Transection

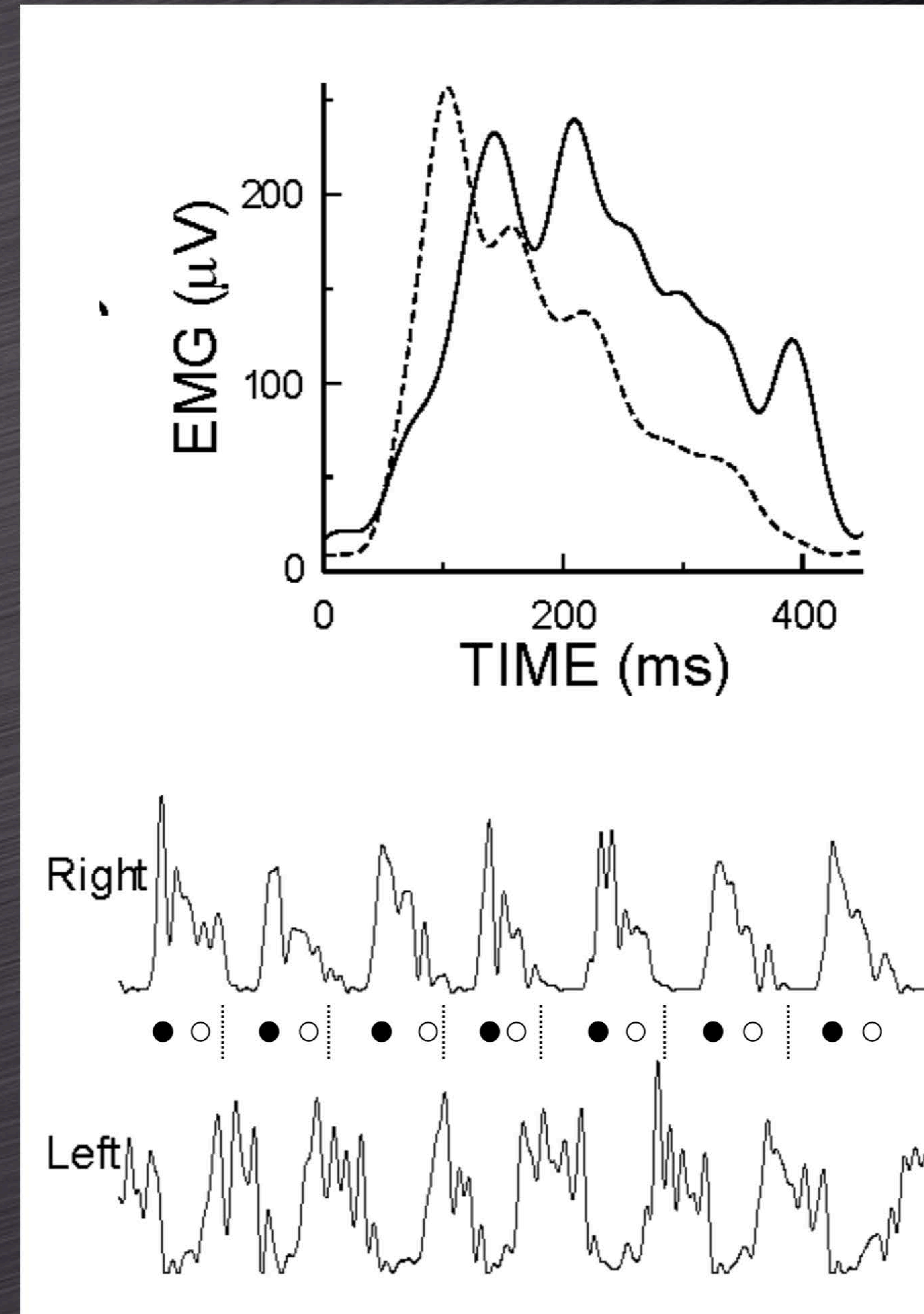


Chen et al J Neurosci 2006

Normal Rat



Rat with Right LC Transection



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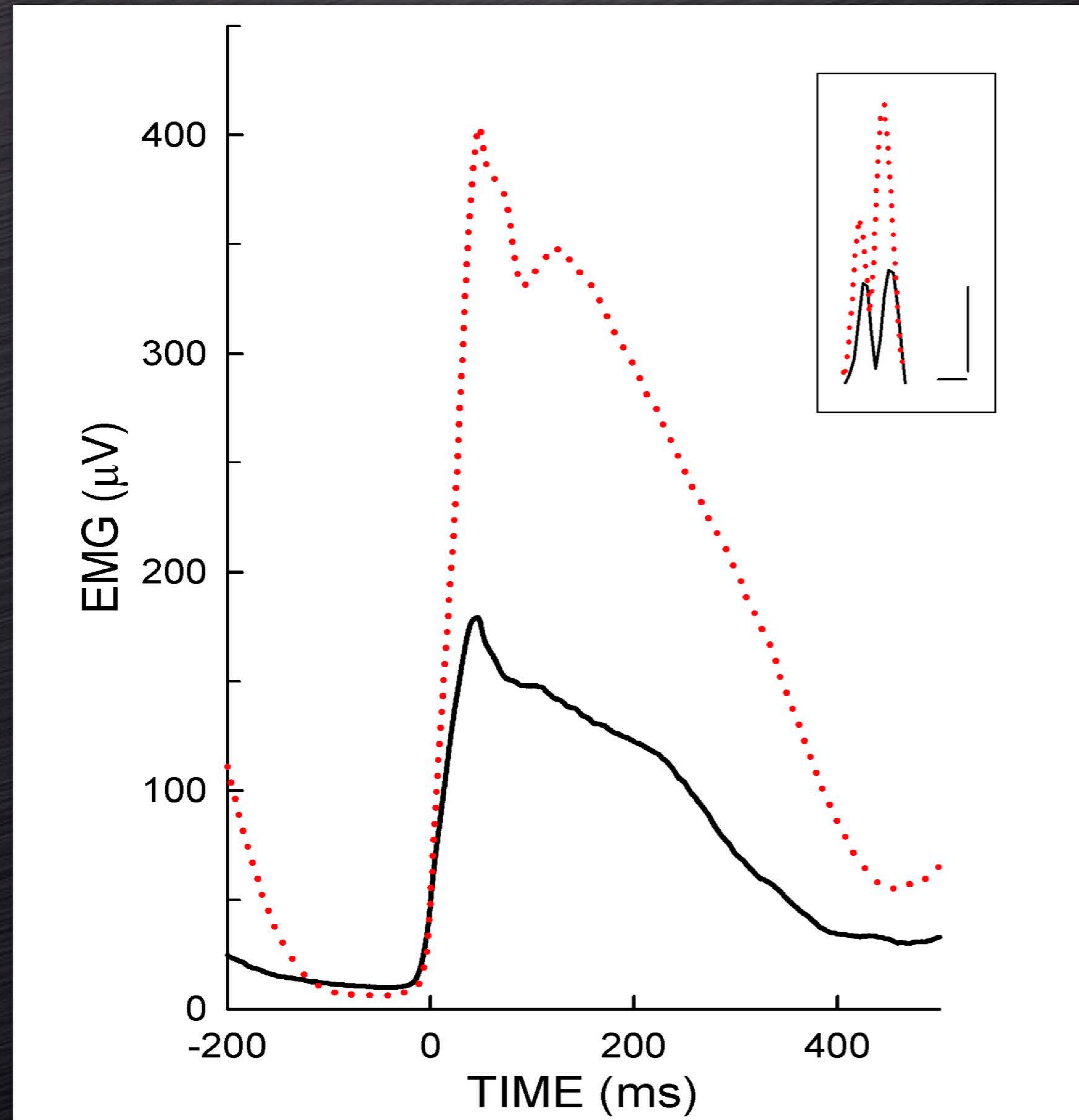
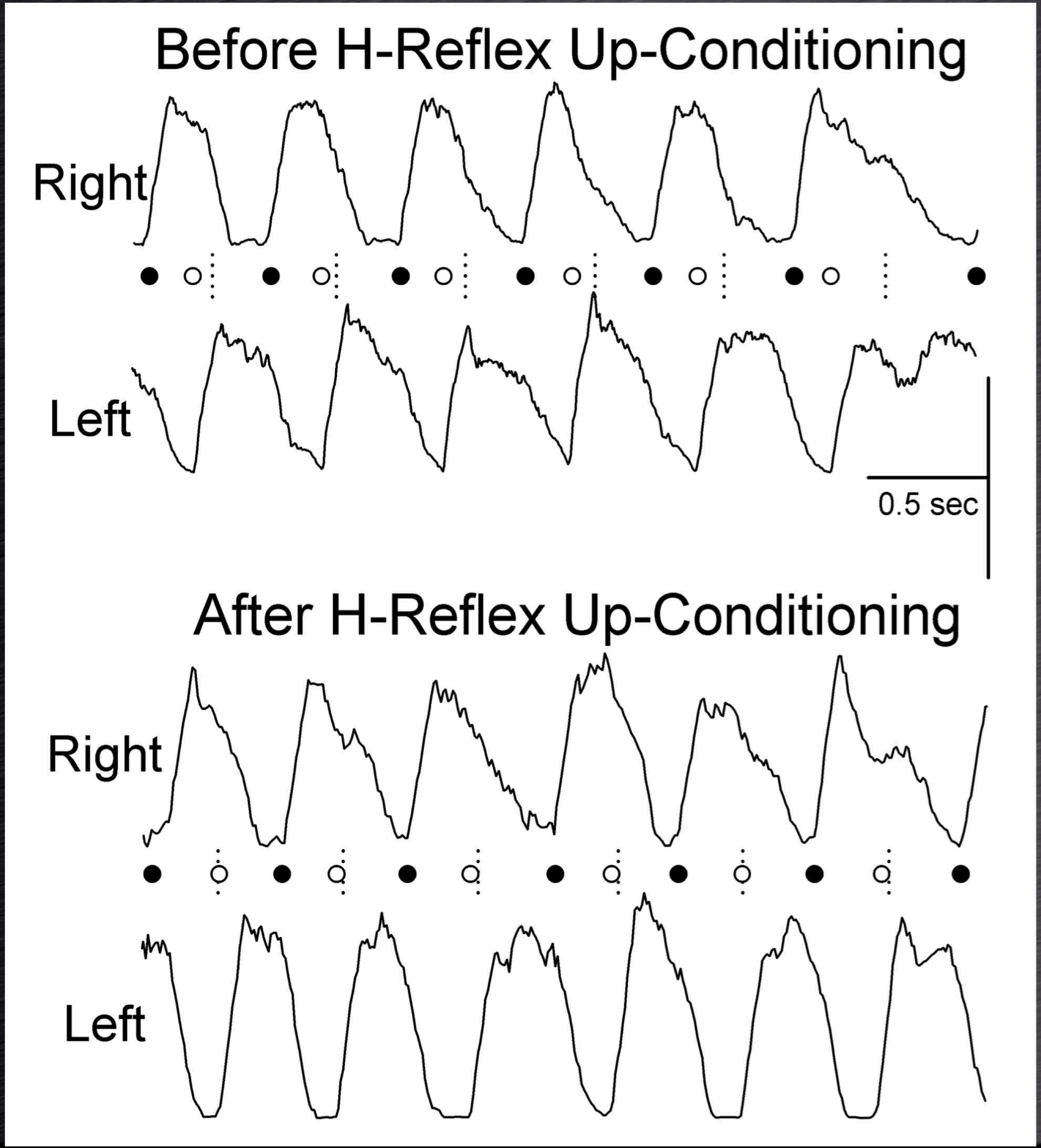
HR up-conditioning increases the soleus burst in an LC rat



Chen et al J Neurosci 2006

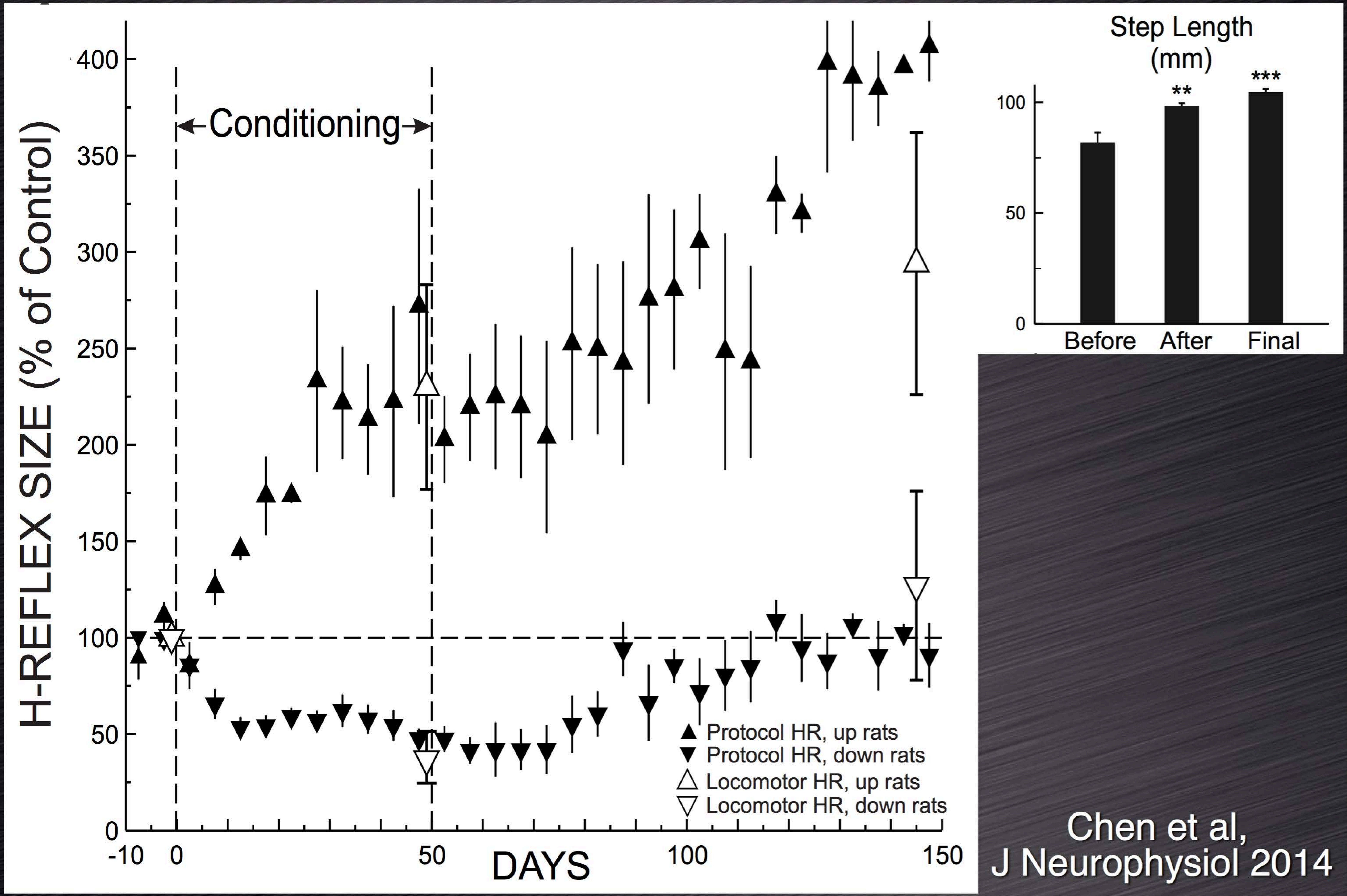
Up-Conditioning in an LC Rat



Appropriate reflex conditioning restores gait symmetry.

Chen et al, J Neurosci 2006

After conditioning ends, beneficial effects persist & increase.

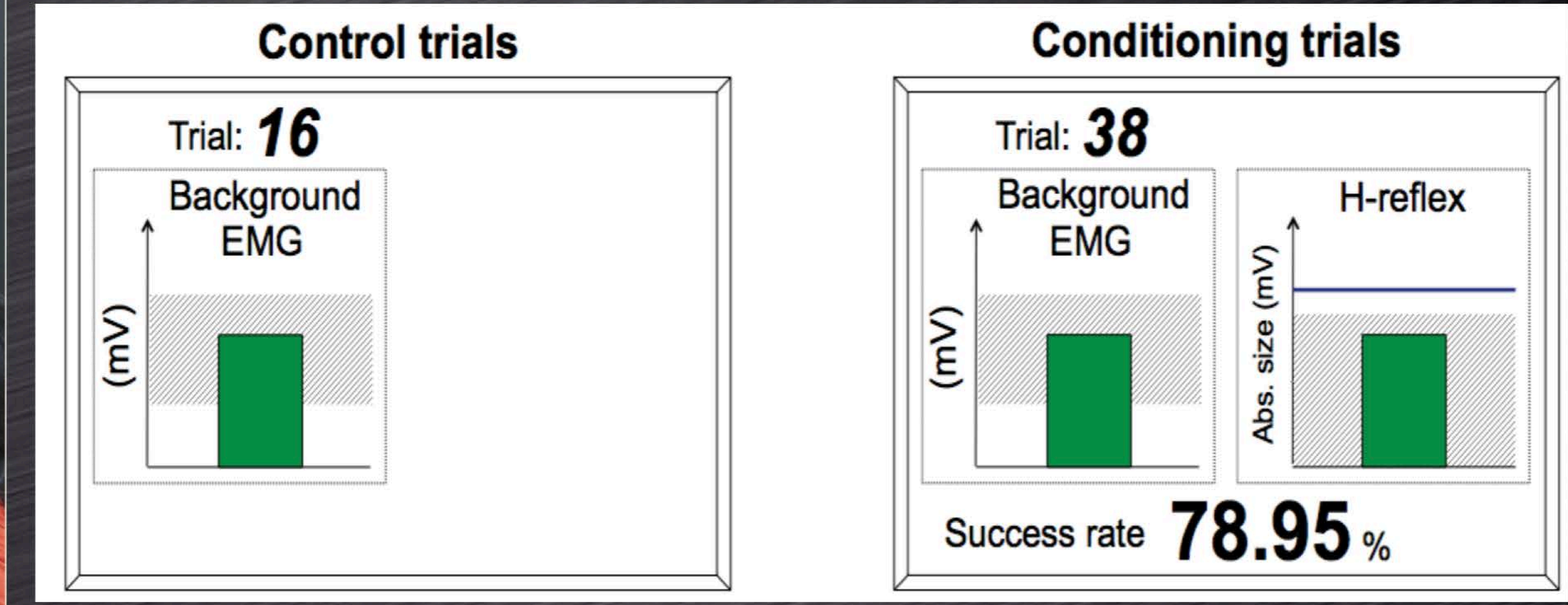


Chen et al,
J Neurophysiol 2014

What about Humans?

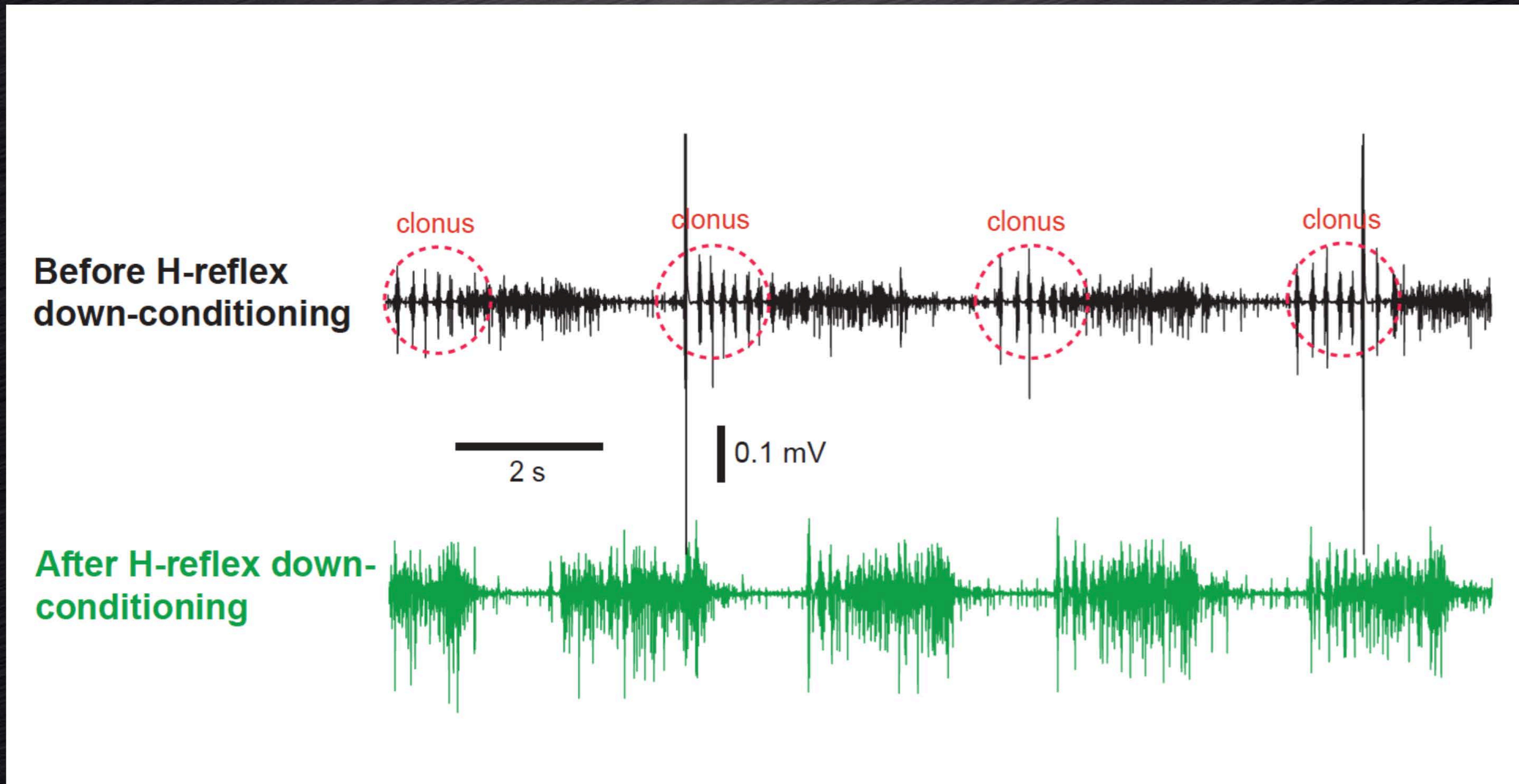
In people with spasticity and footdrop due to SCI, can soleus HRdown conditioning improve locomotion?

Format



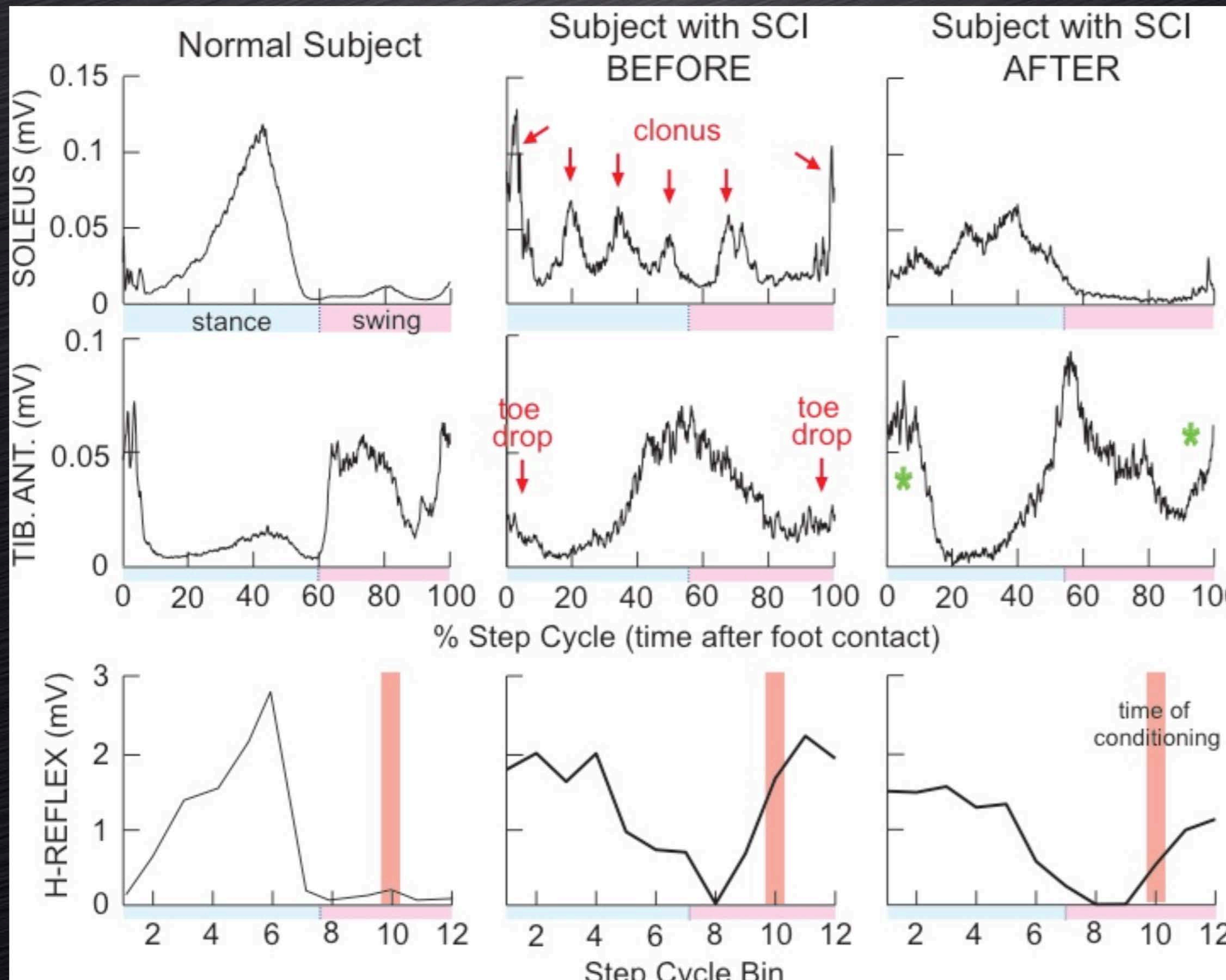
Thompson et al J Neurosci 2013

Improved soleus locomotor EMG activity



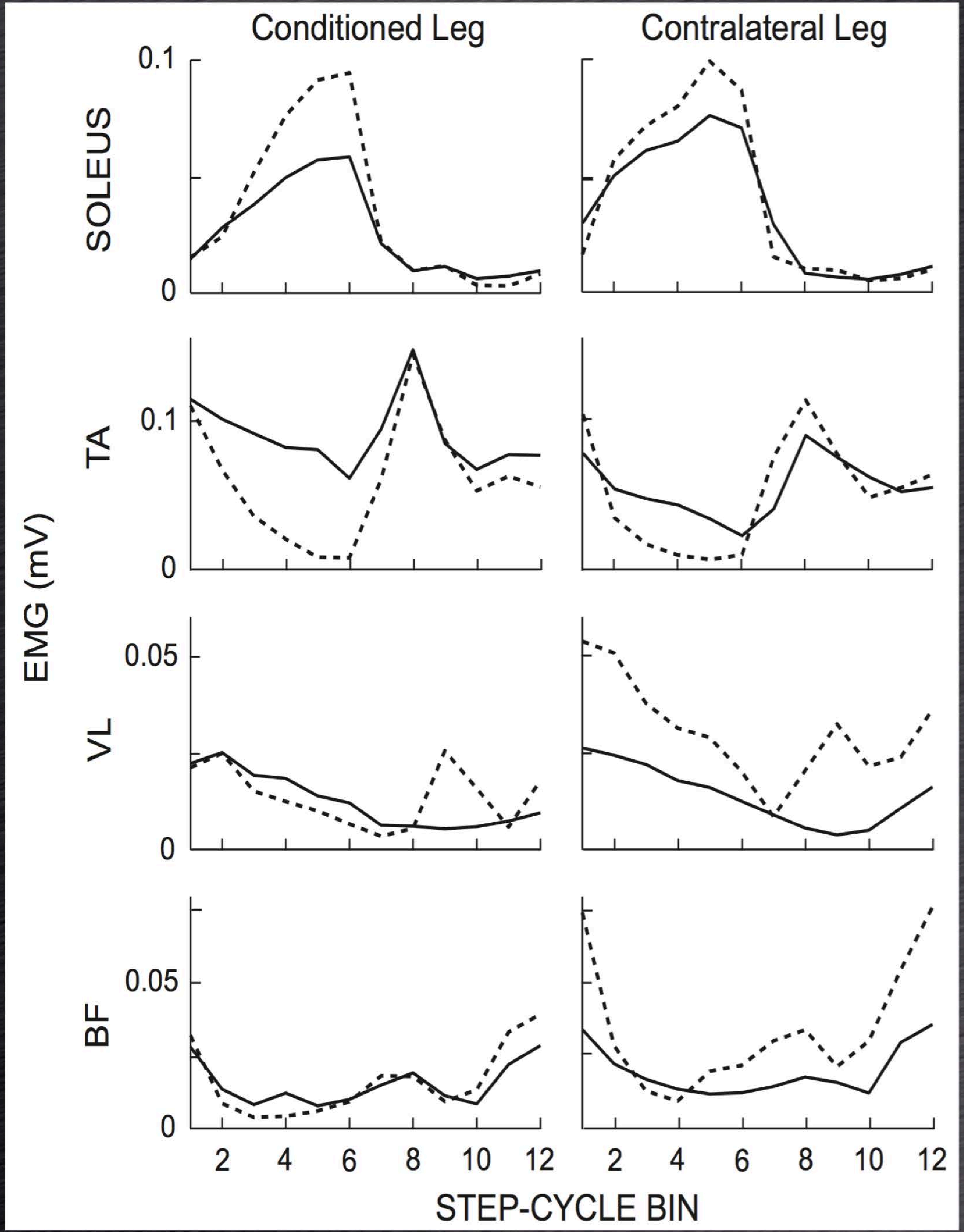
Thompson et al.

Improved soleus *and tibialis anterior* EMG after soleus H-reflex down-conditioning



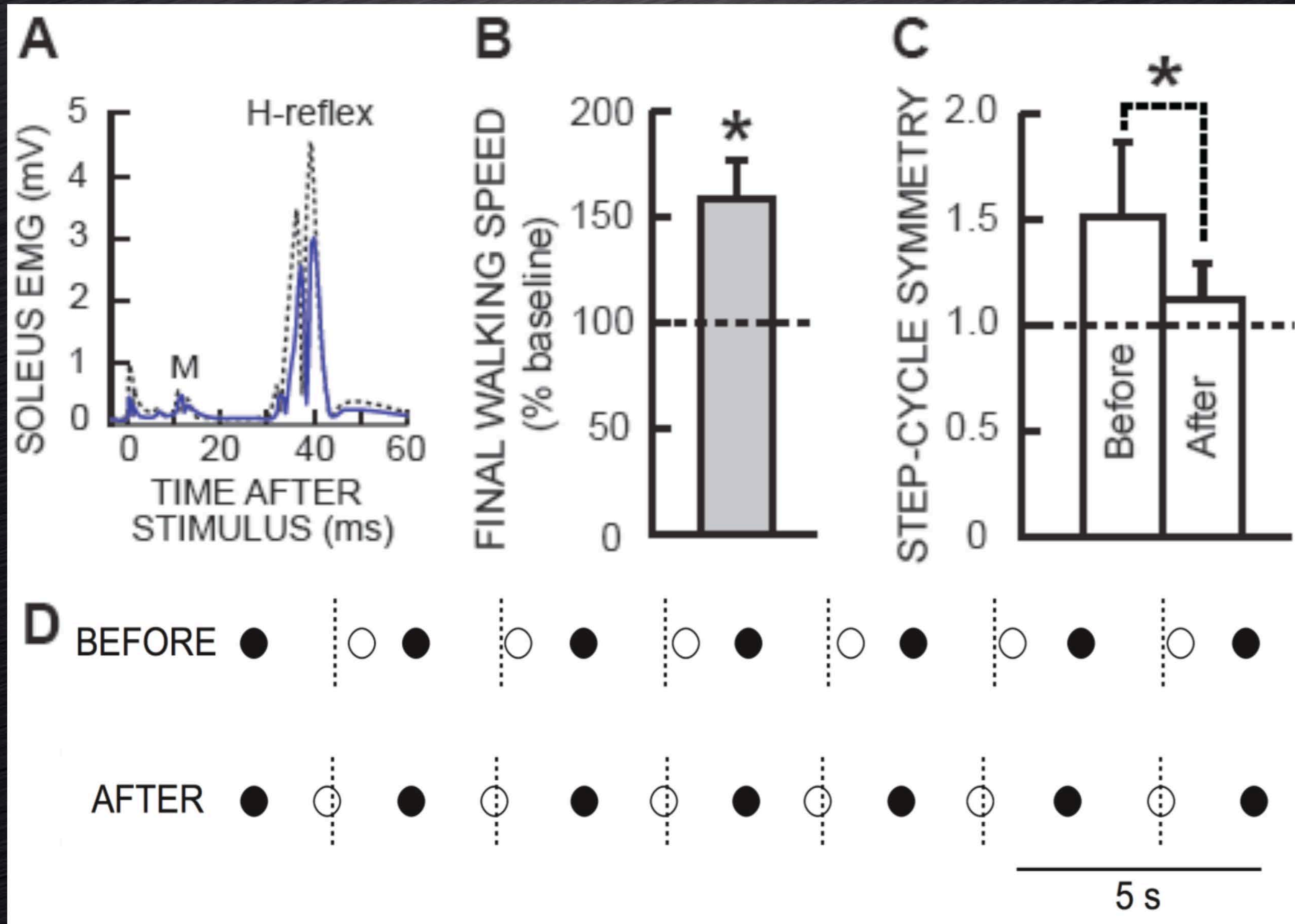
Thompson et al.

The targeted plasticity triggers widespread plasticity



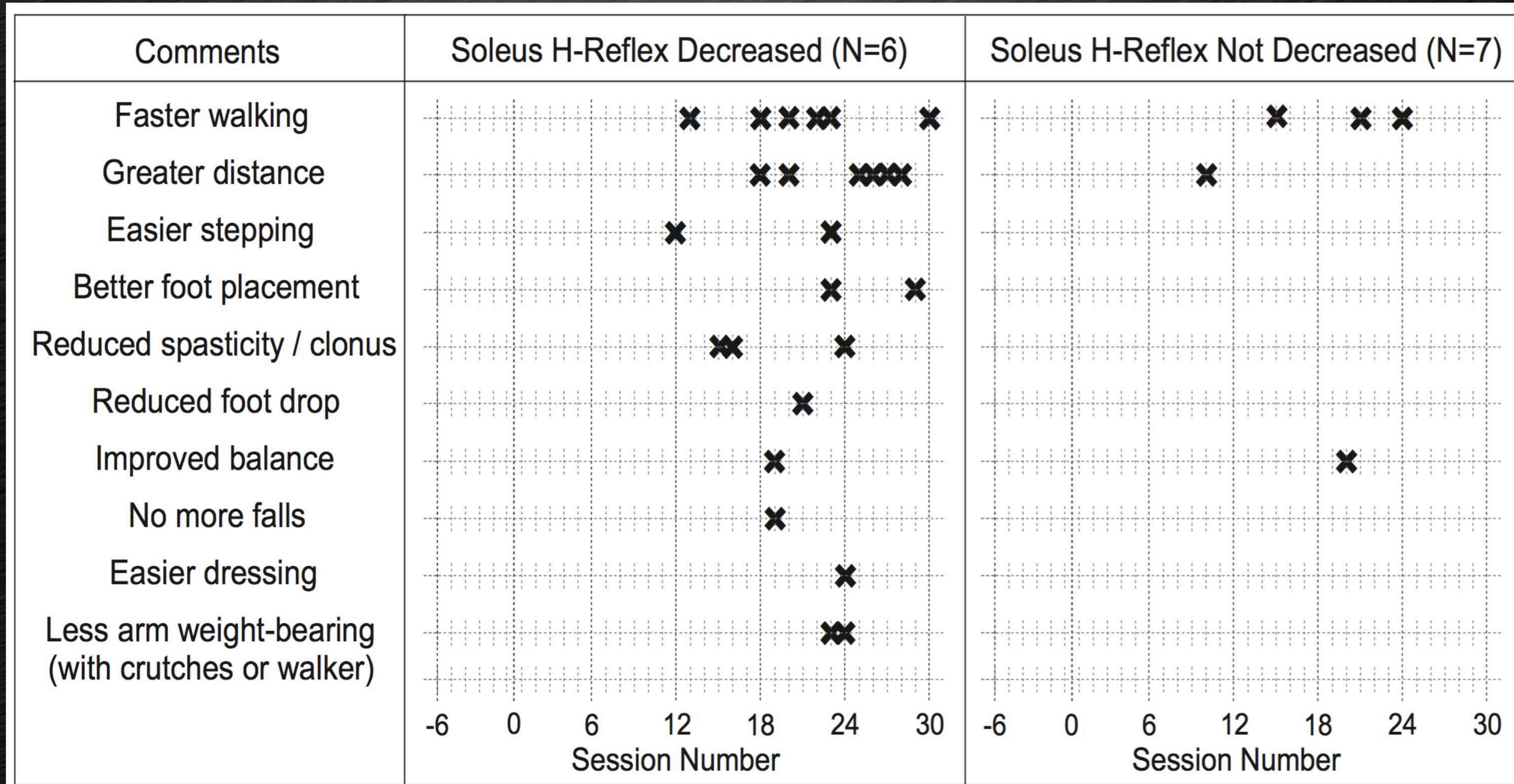
Thompson et al
J Neurosci 2013

Walking speed & symmetry improve



Thompson et al, J Neurosci 2013

Spontaneous Comments



Gait improvement is apparent to the subjects.

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Thompson et al, J Neurosci 2013

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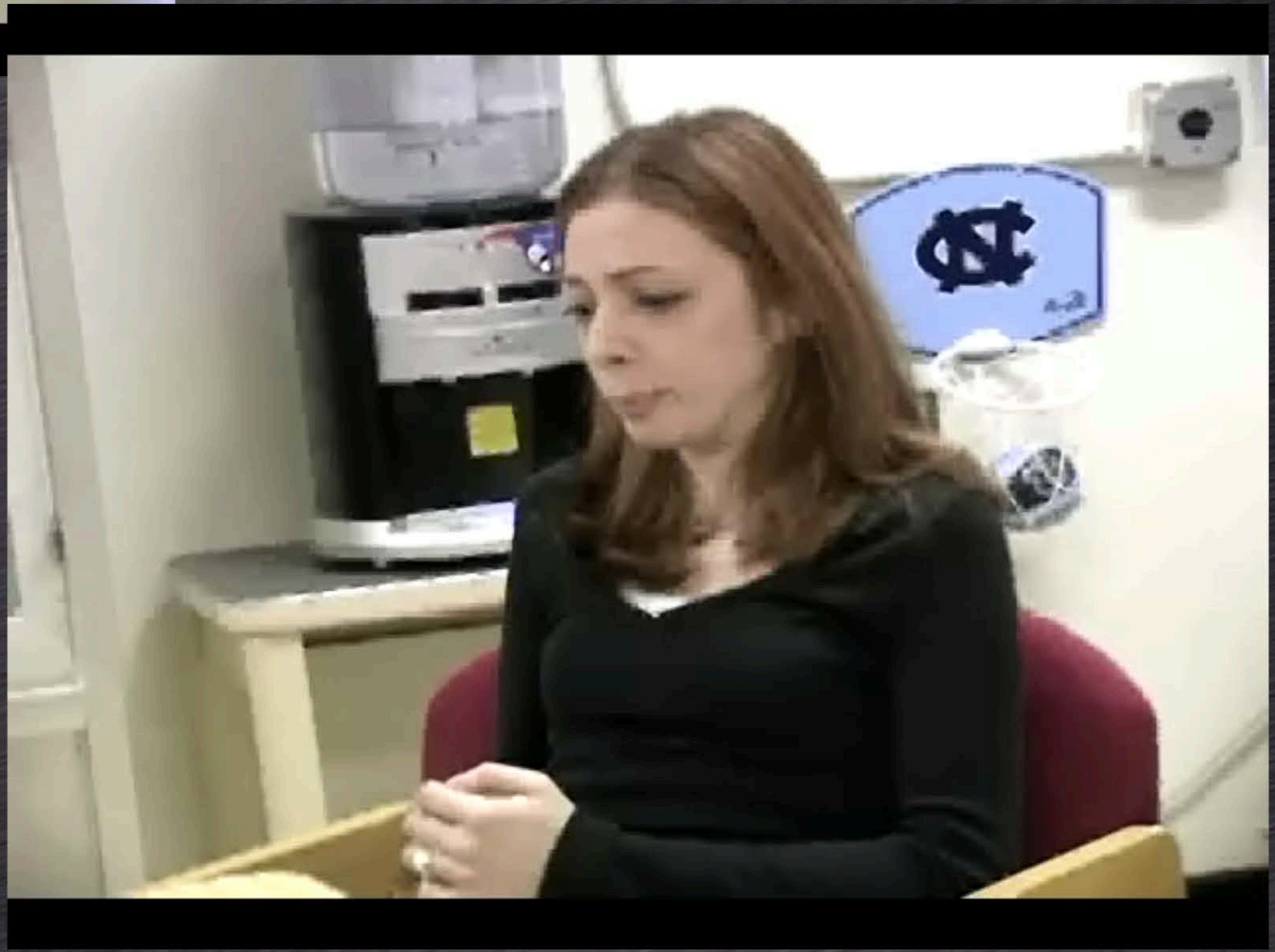


Thompson et al.
Helen Hayes / Wadsworth Center

Summary

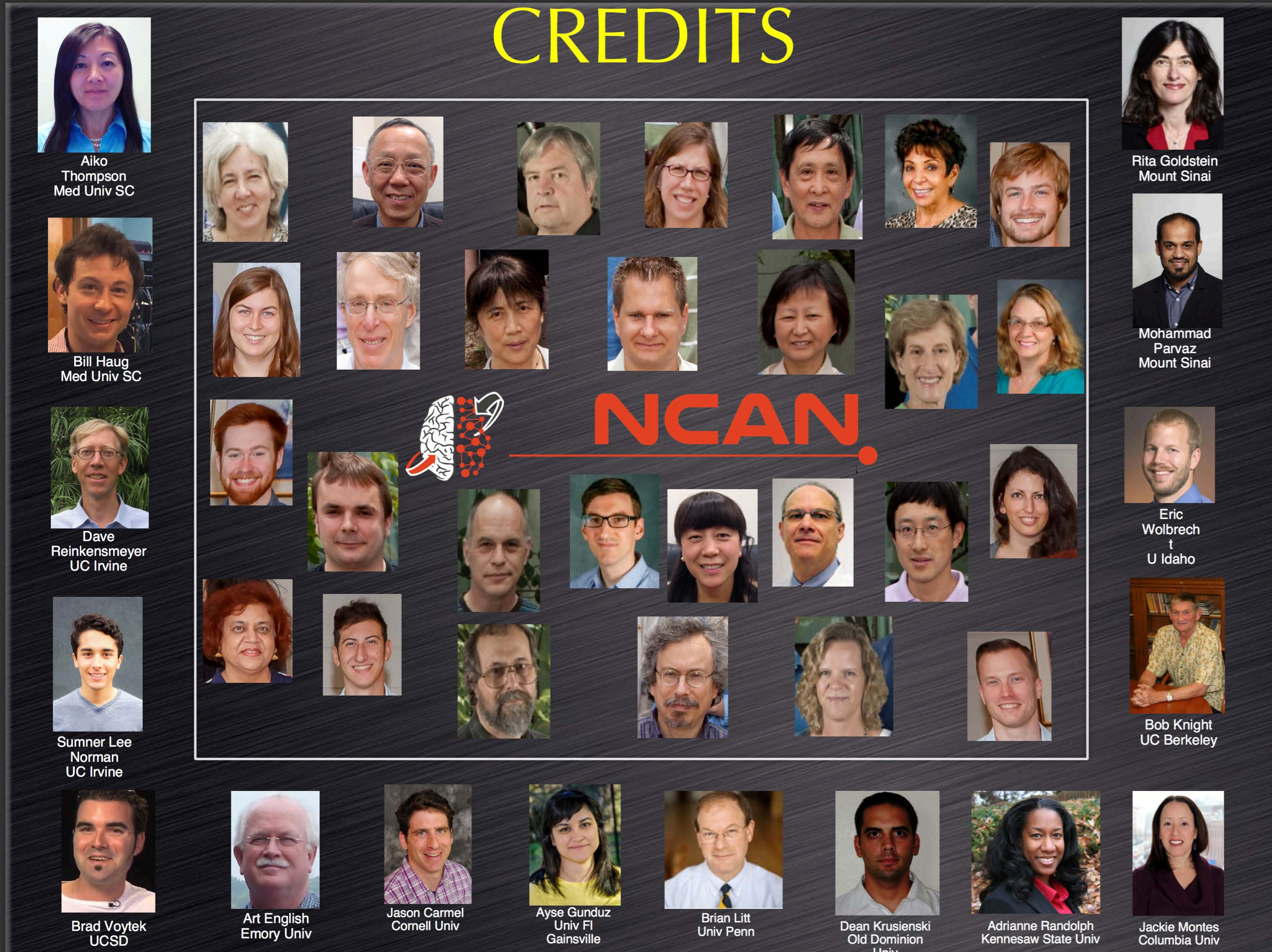
- Recent scientific & technical advances enable a new class of technologies that interact directly with the CNS.

- Brain-computer interfaces (BCIs) to restore communication & control.

- BCIs to enhance rehabilitation.

- Safe rapid cortical mapping prior to surgery.

- Protocols that target beneficial plasticity to critical sites and trigger wider beneficial plasticity.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NEC Foundation
Brain Communication Foundation
NYS Spinal Cord Injury Research Trust

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ANNOUNCEMENT

NIH Short Course in Adaptive Neurotechnologies
Albany, New York

July 10-28, 2017
&
July, 2018

Thank you!

Questions?